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(54) **FILE CLONES IN A DISTRIBUTED FILE SYSTEM**

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(22) Filed: **Jun. 29, 2012**

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G06F 13/00	(2006.01)
G06F 13/28	(2006.01)
G06F 3/06	(2006.01)

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CPC ***G06F 3/0608*** (2013.01); ***G06F 3/067*** (2013.01); ***G06F 3/0641*** (2013.01); *G06F 3/064* (2013.01); *G06F 3/0643* (2013.01)

(58) **Field of Classification Search**
CPC . G06F 11/14; G06F 11/1446; G06F 11/1464; G06F 3/0643; G06F 3/0608; G06F 3/067; G06F 3/064; G06F 3/0641
USPC 711/161–162; 712/228; 707/781, 782, 707/783, 784, 785, 786, 787, 788, 789, 707/821–831, E17.01, 999.202, 999.001, 707/999.2, 999.01, 999.102
See application file for complete search history.

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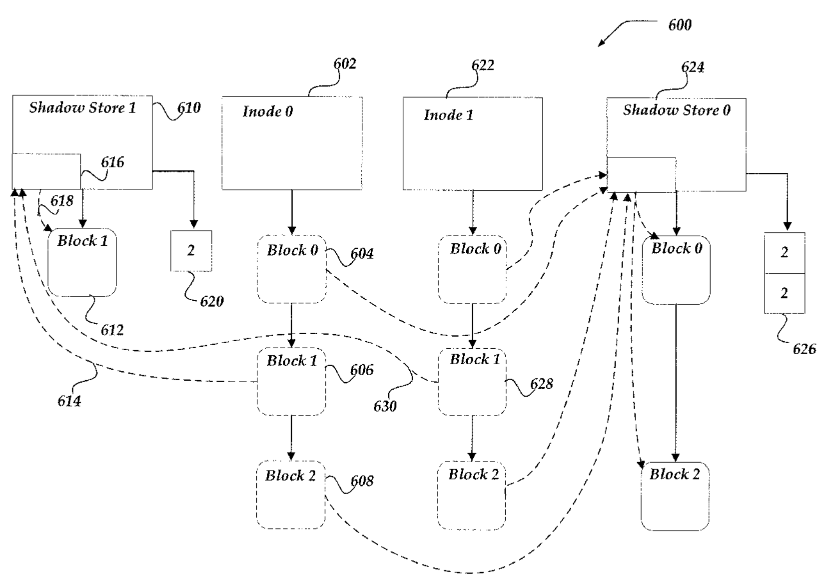
(57) **ABSTRACT**

Embodiments are directed towards cloning files in a distributed file system. In response to a request to create file clones, a file cloning application can be employed to generate file clones based on a source file. The file cloning application can generate a new inode for each new file clone and at least one new shadow store. Data blocks from the source file can be transferred to the shadow store. The transferred data blocks can be replaced with reference blocks that point to the data blocks transferred to the shadow store. Likewise, additional reference blocks pointing to data blocks in the shadow store can be generated for the new file clone inodes. Further, the shadow store can maintain reference counters that track the number of reference blocks pointing to each shadow store block. Also, file clones can be generated based on a point-in-time snapshot of the source file.

24 Claims, 22 Drawing Sheets



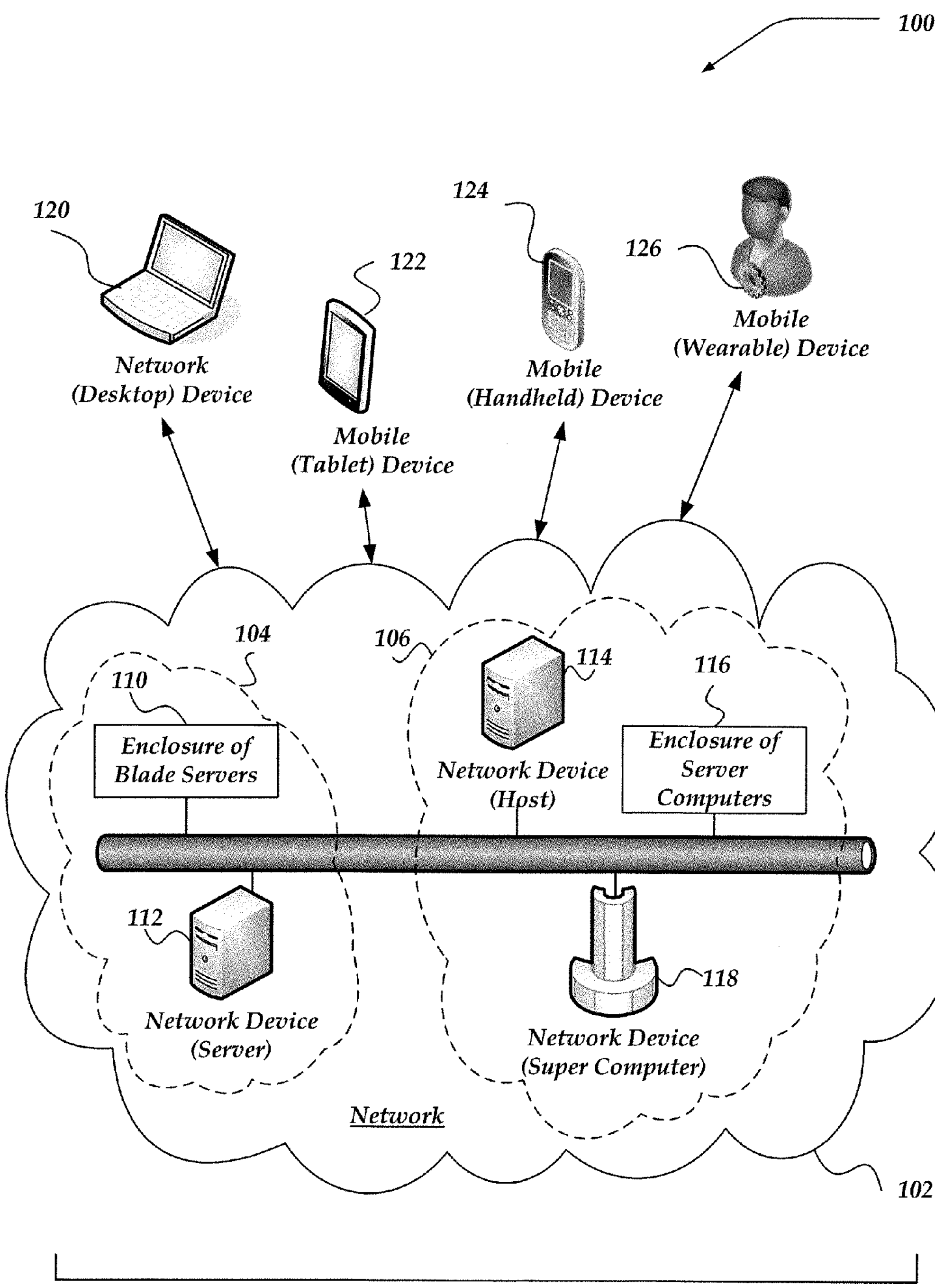

100
120
Network
(Desktop) Device
122
Mobile
(Tablet) Device
124
Mobile
(Handheld) Device
126
Mobile
(Wearable) Device
104
106
110
Enclosure of
Blade Servers
114
Network Device
(Host)
116
Enclosure of
Server
Computers
112
Network Device
(Server)
118
Network Device
(Super Computer)
Network
102

Fig. 1

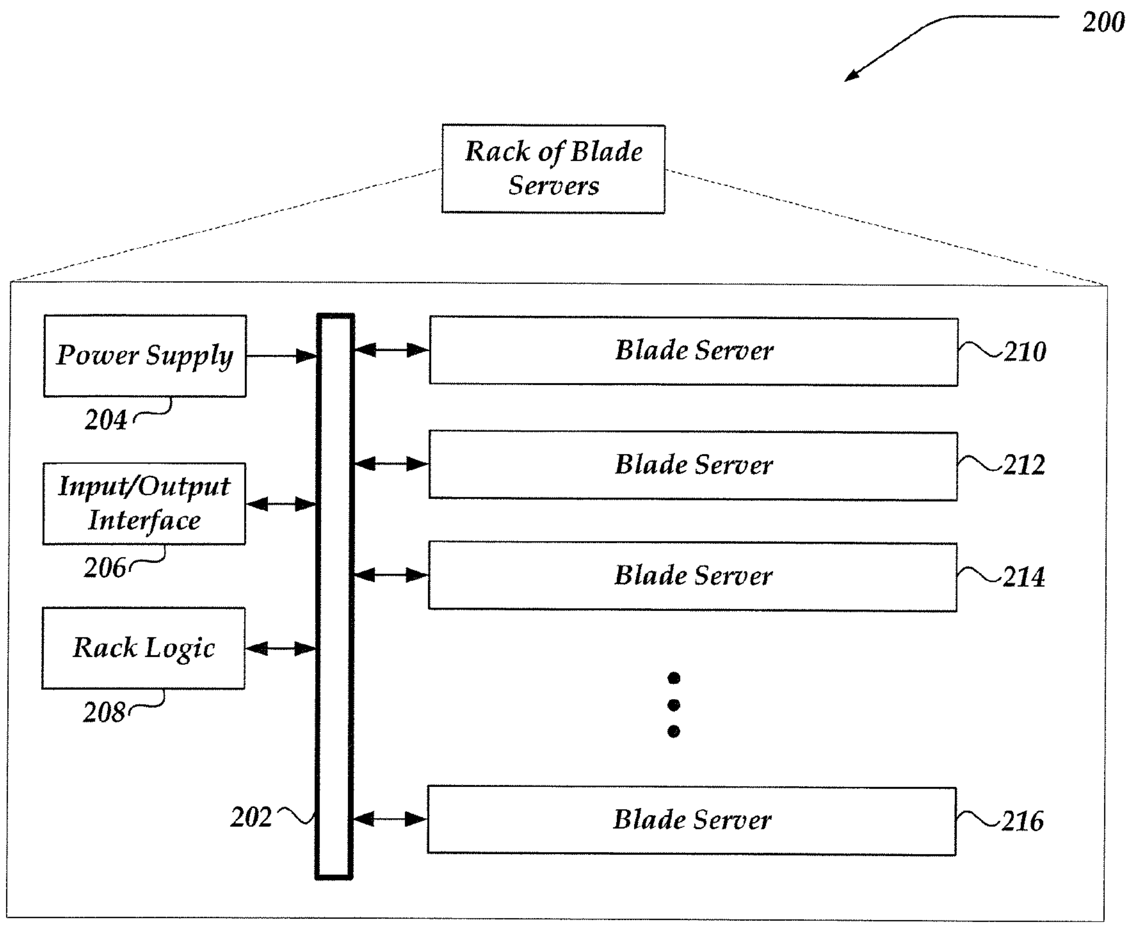

200
Rack of Blade Servers
Power Supply
204
Input/Output Interface
206
Rack Logic
208
202
Blade Server
210
Blade Server
212
Blade Server
214
Blade Server
216

Fig. 2A

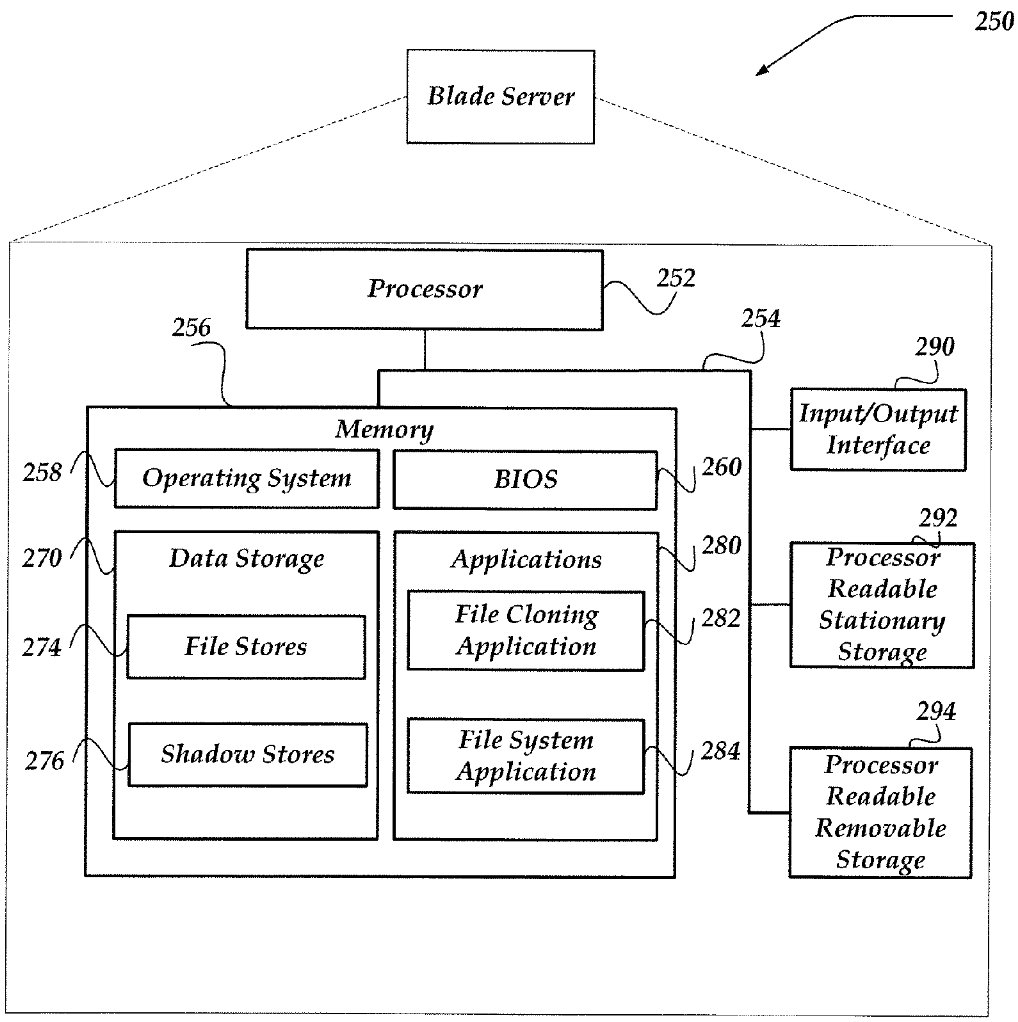

250
Blade Server
Processor
252
254
256
290
Memory
Input/Output Interface
258
Operating System
BIOS
260
270
Data Storage
Applications
280
292
Processor Readable Stationary Storage
274
File Stores
File Cloning Application
282
276
Shadow Stores
File System Application
284
294
Processor Readable Removable Storage

Fig. 2B

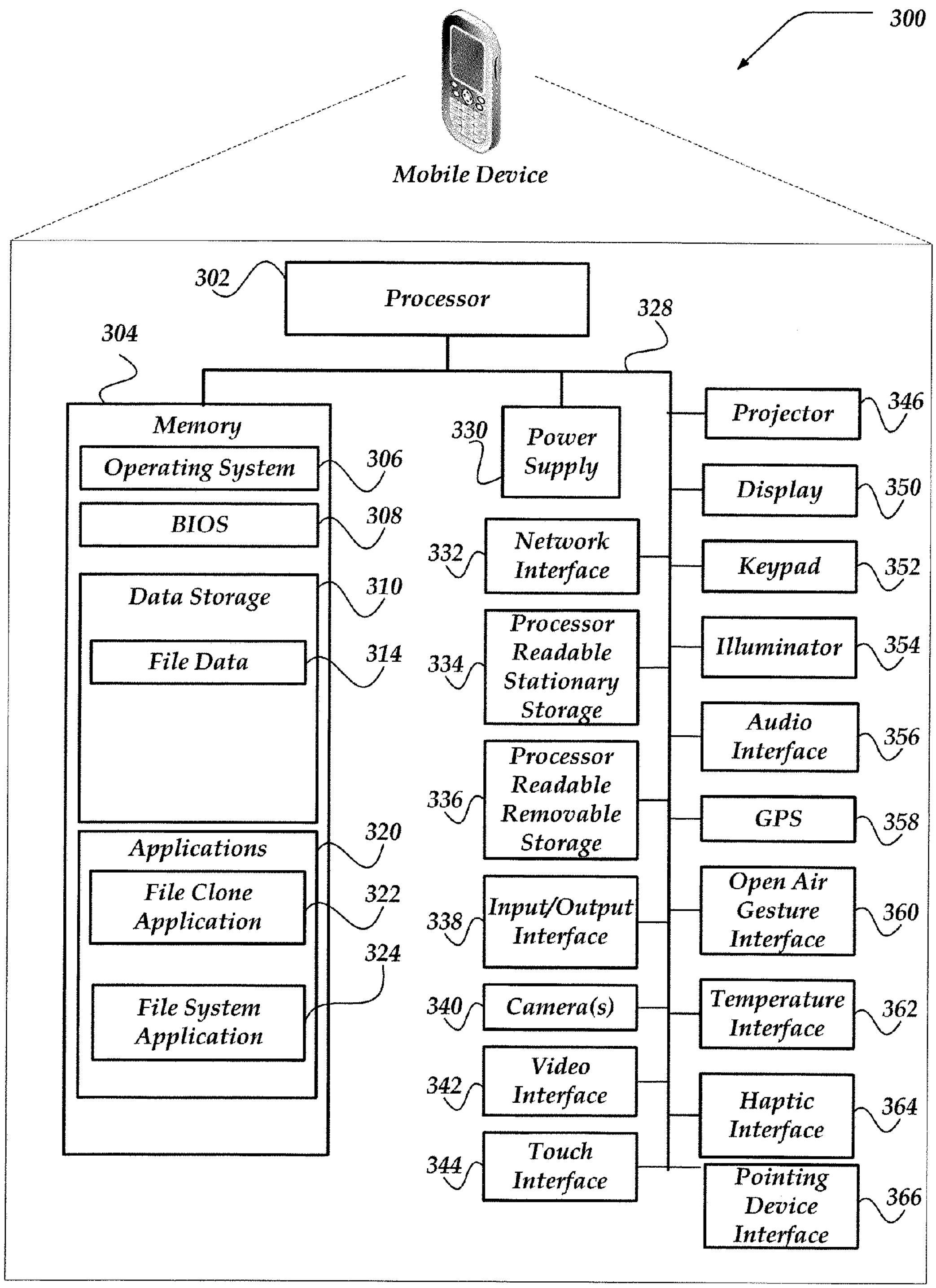

300
Mobile Device
Processor
302
304
328
Memory
Operating System
306
BIOS
308
Data Storage
310
File Data
314
Applications
320
File Clone Application
322
324
File System Application
330
Power Supply
332
Network Interface
334
Processor Readable Stationary Storage
336
Processor Readable Removable Storage
338
Input/Output Interface
340
Camera(s)
342
Video Interface
344
Touch Interface
Projector
346
Display
350
Keypad
352
Illuminator
354
Audio Interface
356
GPS
358
Open Air Gesture Interface
360
Temperature Interface
362
Haptic Interface
364
Pointing Device Interface
366

Fig. 3

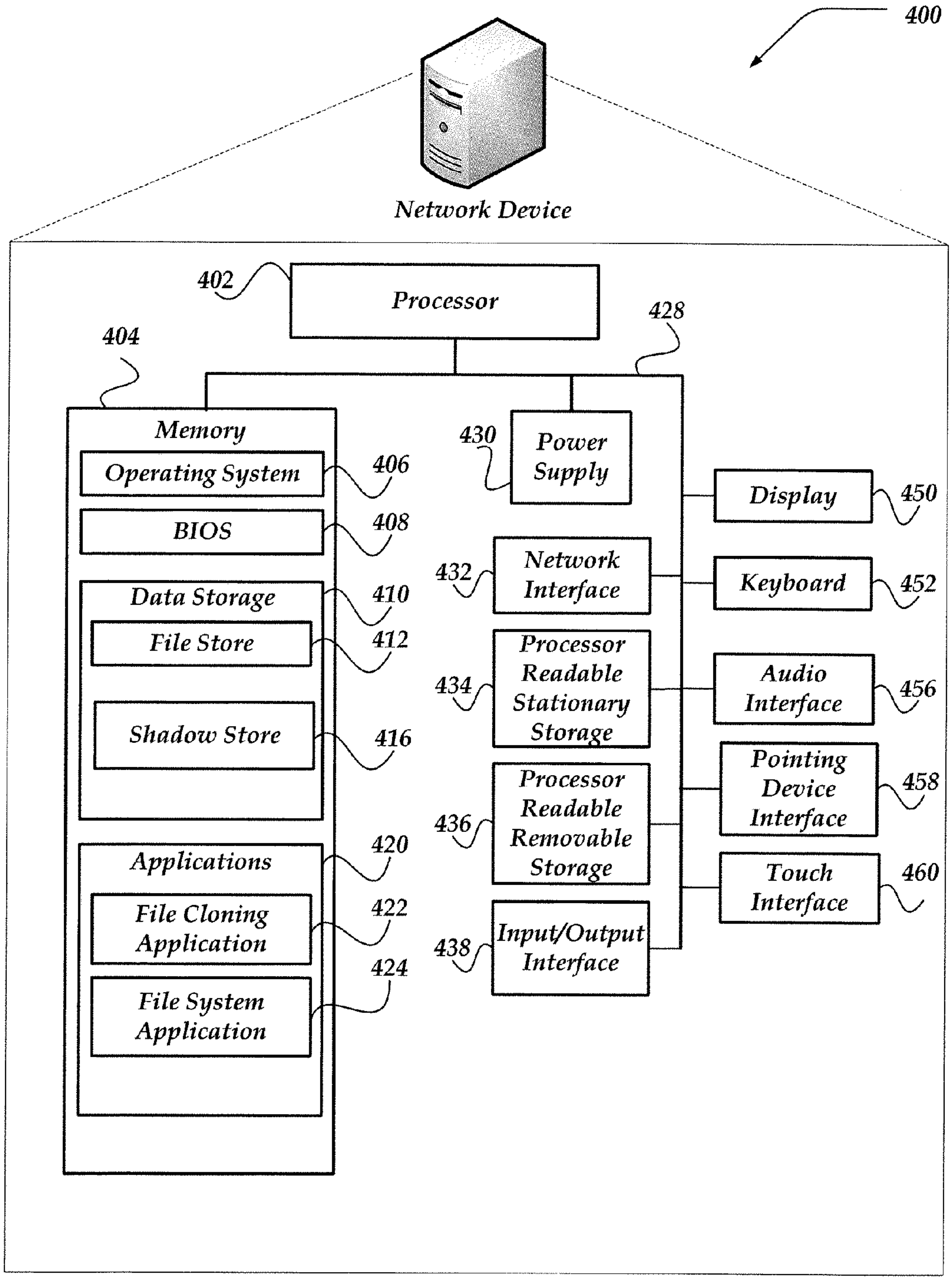

400
Network Device
Processor
402
428
404
Memory
Operating System
406
BIOS
408
Data Storage
410
File Store
412
Shadow Store
416
Applications
420
File Cloning Application
422
File System Application
424
430
Power Supply
432
Network Interface
434
Processor Readable Stationary Storage
436
Processor Readable Removable Storage
438
Input/Output Interface
Display
450
Keyboard
452
Audio Interface
456
Pointing Device Interface
458
Touch Interface
460

Fig. 4

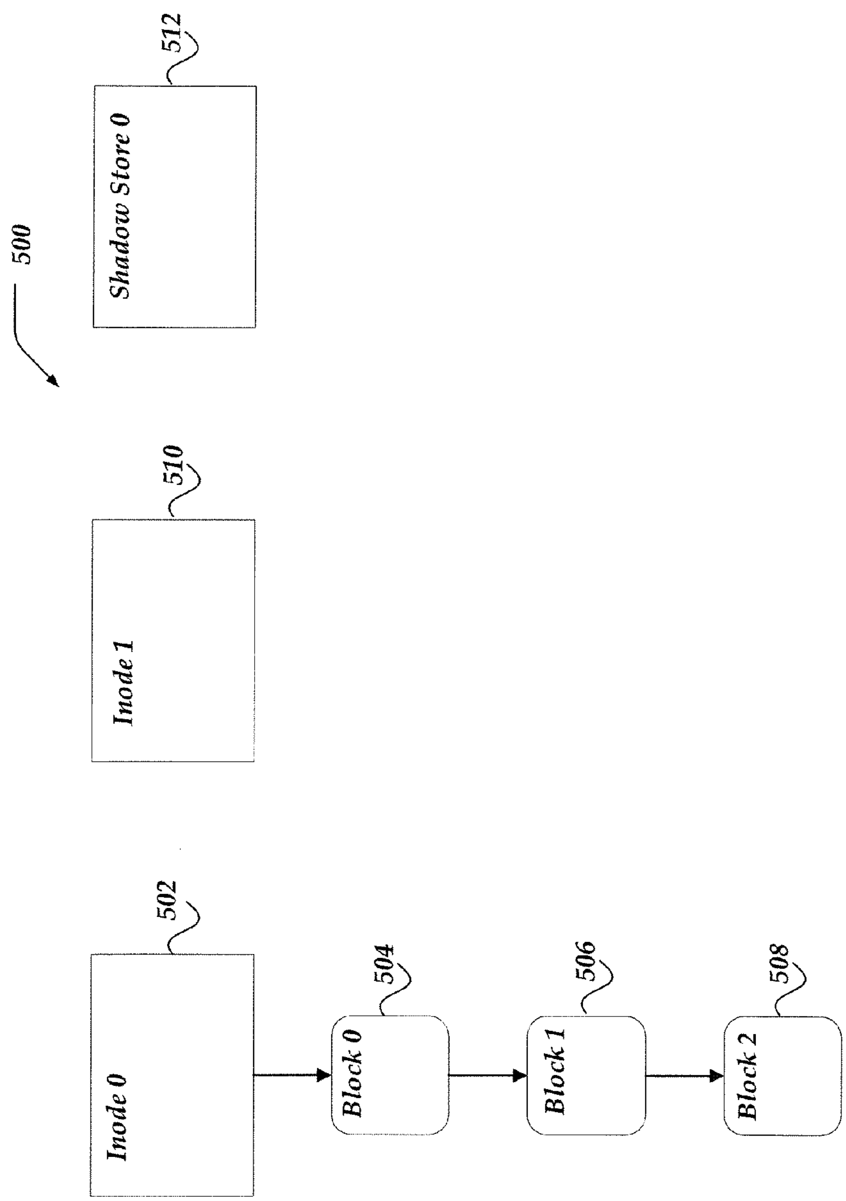

500
Shadow Store 0
512
Inode 1
510
Inode 0
502
Block 0
504
Block 1
506
Block 2
508

Fig. 5A

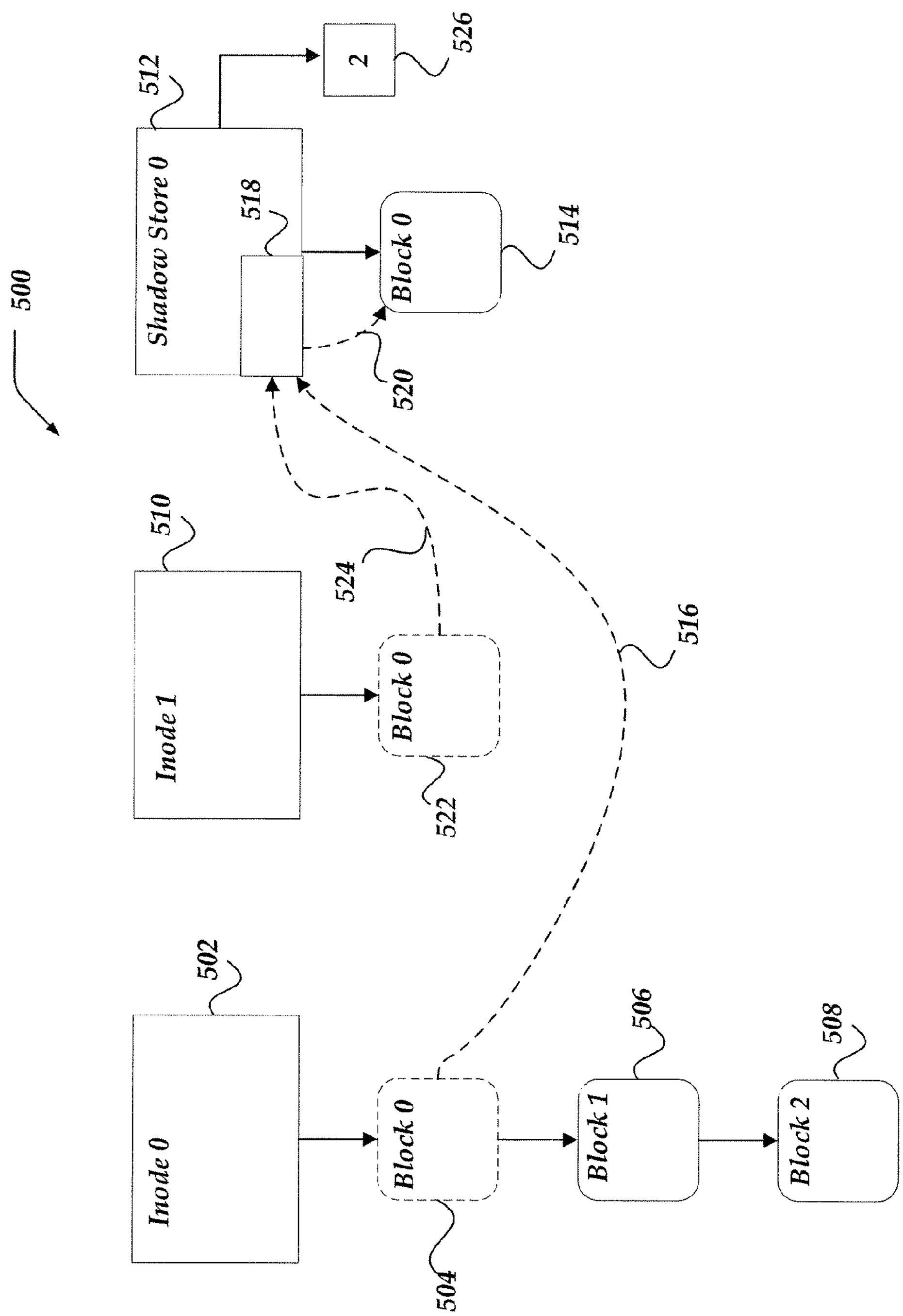

500
Shadow Store 0
512
2
526
518
Block 0
514
520
Inode 1
510
Block 0
522
524
516
Inode 0
502
Block 0
504
Block 1
506
Block 2
508

Fig. 5B

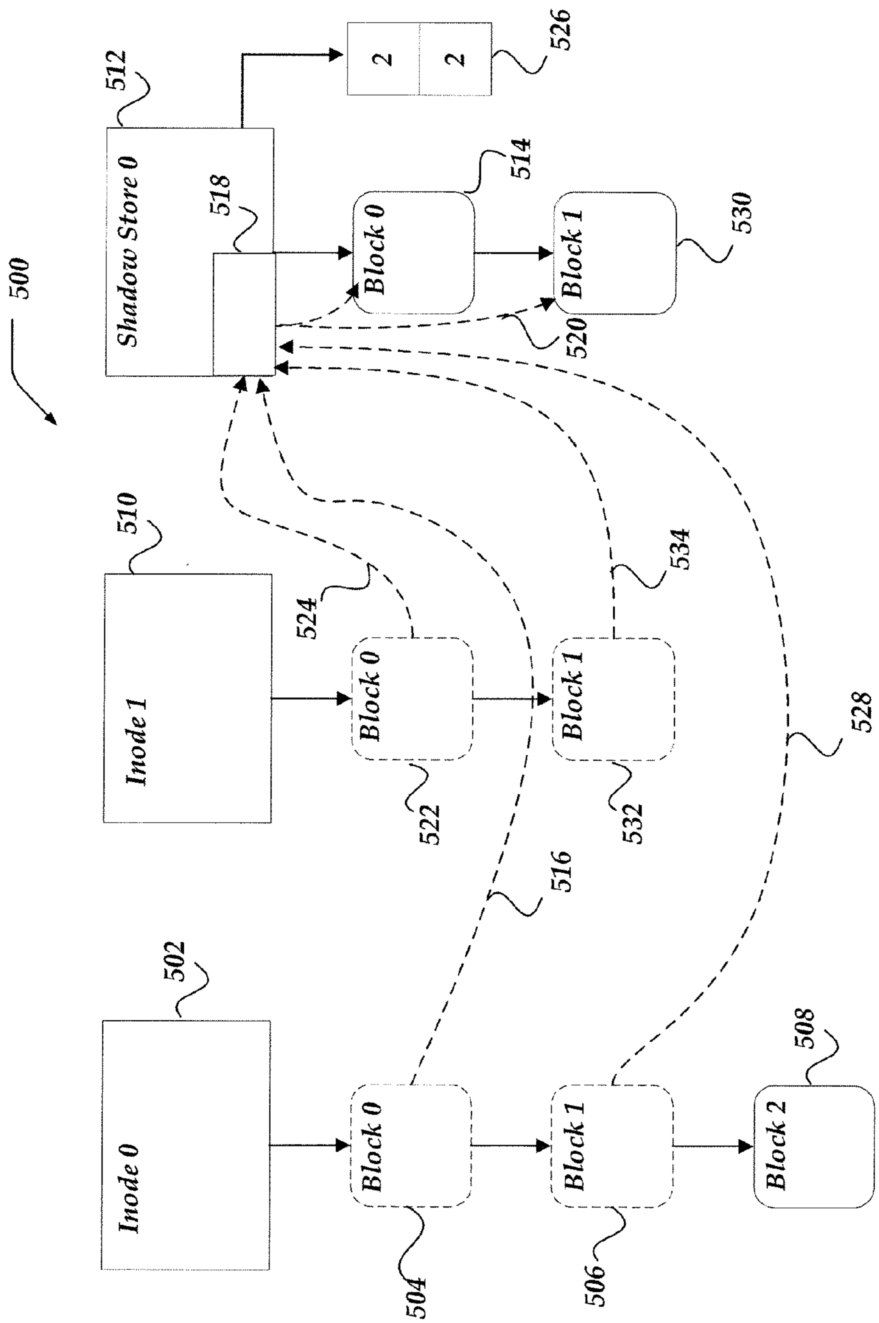

500
Shadow Store 0
512
518
2
2
526
Block 0
514
Block 1
530
520
Inode 1
510
Block 0
524
Block 1
534
522
532
516
528
Inode 0
502
Block 0
Block 1
Block 2
508
504
506

Fig. 5C

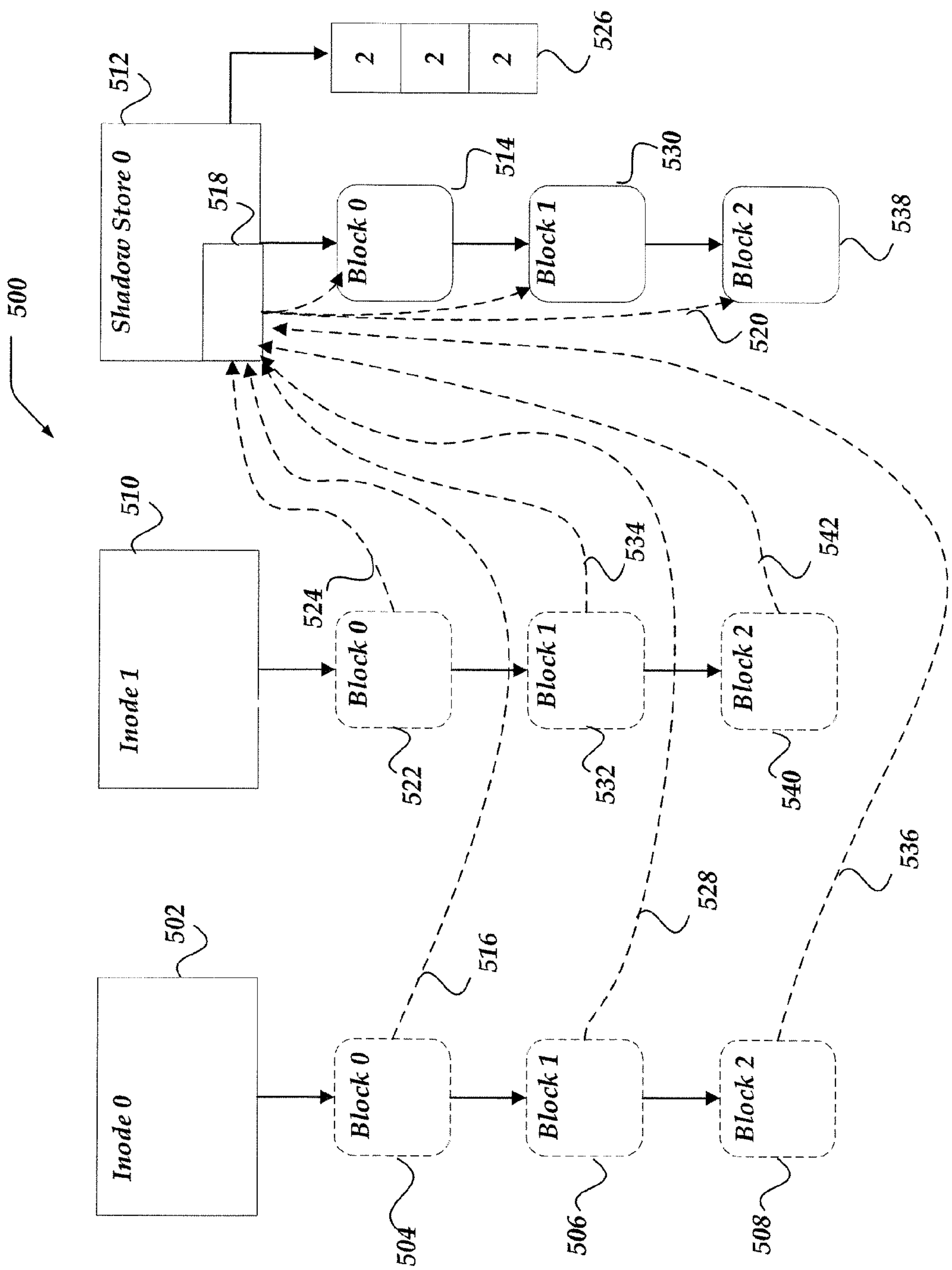

500
Shadow Store 0
512
518
2
2
2
526
Block 0
514
Block 1
530
Block 2
538
520
Inode 1
510
Block 0
522
524
Block 1
532
534
Block 2
540
542
Inode 0
502
Block 0
504
516
Block 1
506
528
Block 2
508
536

Fig. 5D

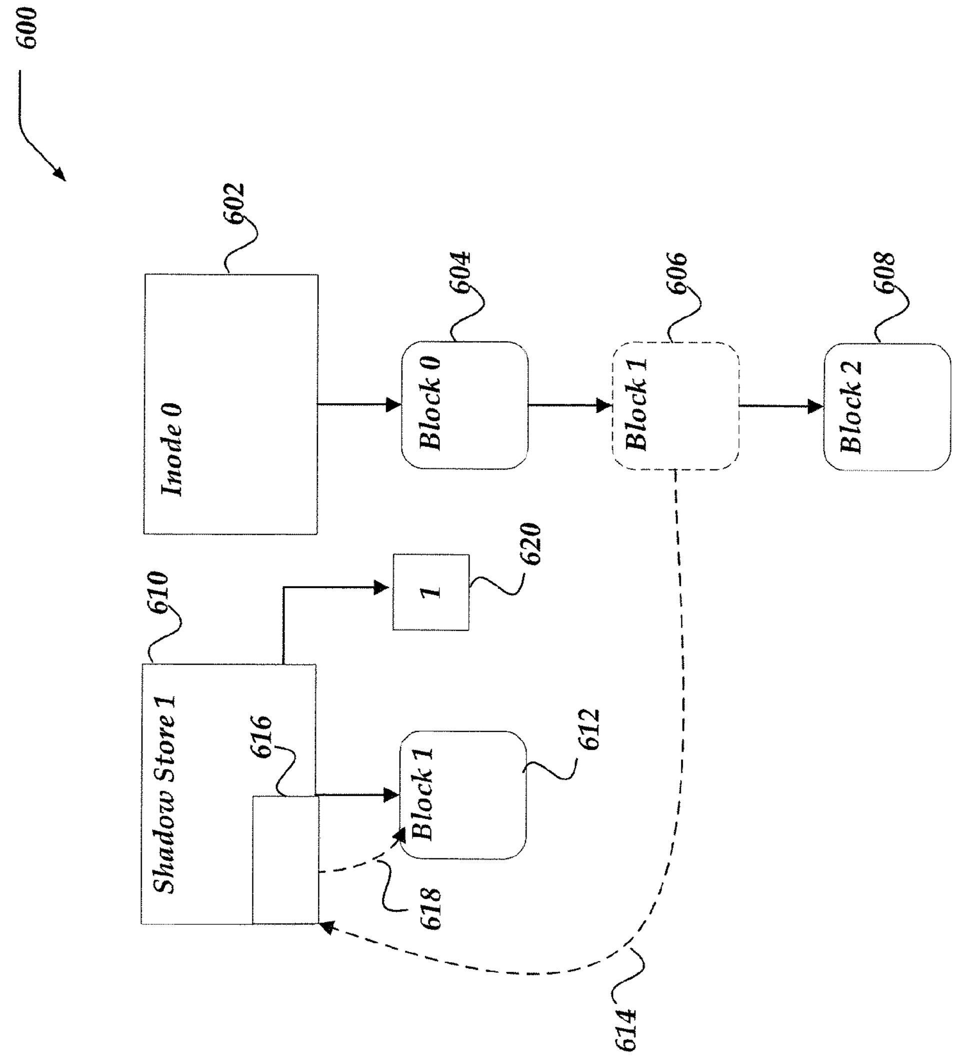

600
602
Inode 0
604
Block 0
606
Block 1
608
Block 2
610
Shadow Store 1
620
1
616
Block 1
612
618
614

Fig. 6A

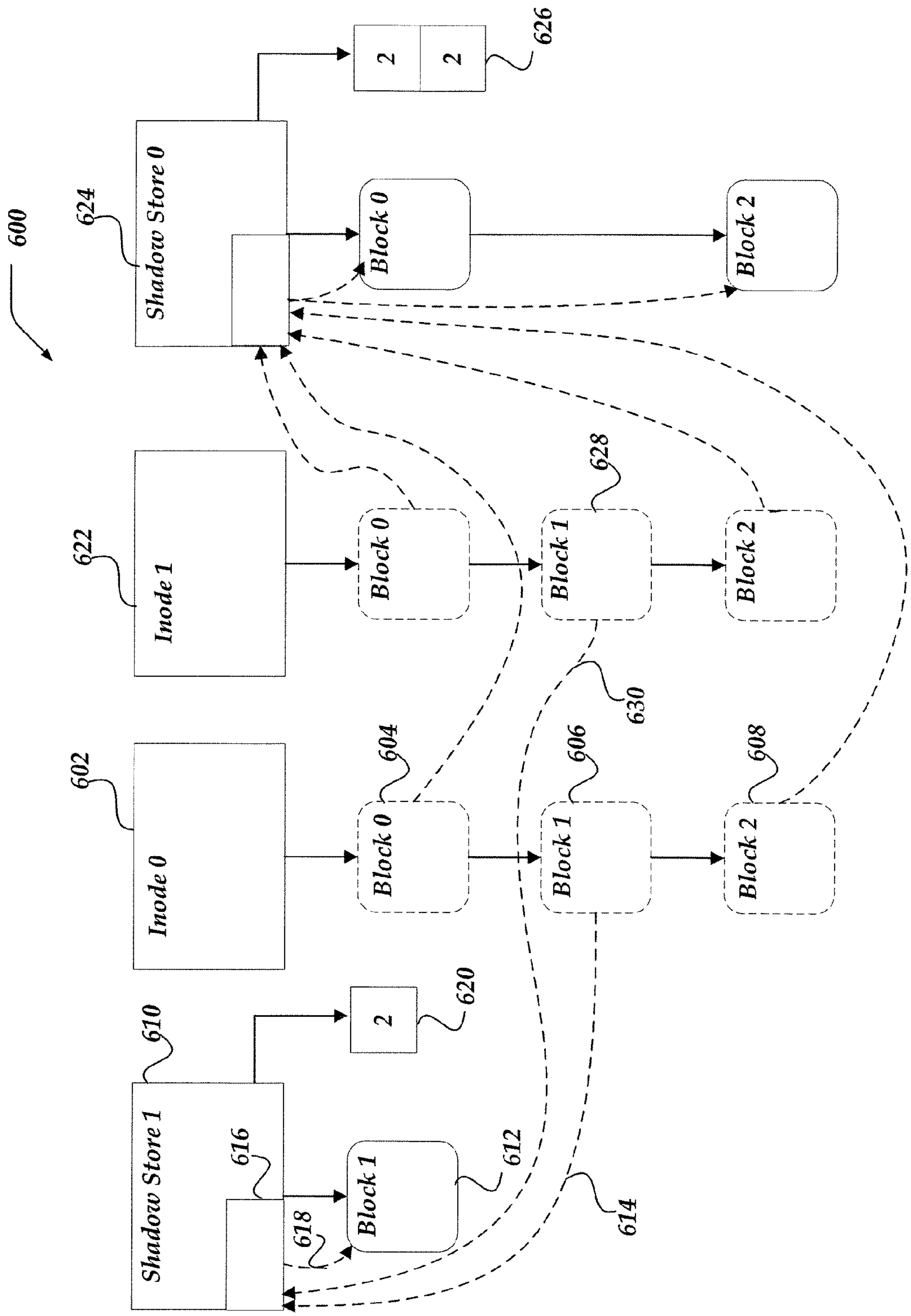

600
Shadow Store 0
624
2
2
626
Block 0
Block 2
Inode 1
622
Block 0
Block 1
628
Block 2
630
Inode 0
602
Block 0
604
Block 1
606
Block 2
608
Shadow Store 1
610
2
620
616
Block 1
612
618
614

Fig. 6B

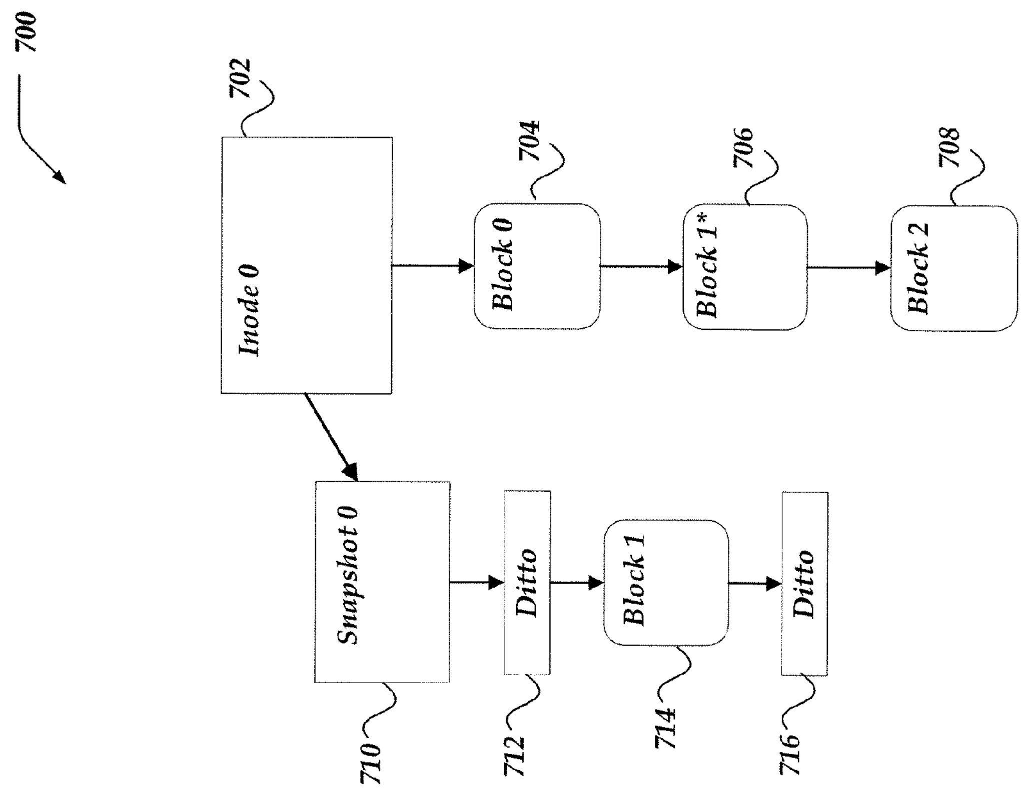

700
702
Inode 0
704
Block 0
706
Block 1*
708
Block 2
Snapshot 0
710
Ditto
712
Block 1
714
Ditto
716

Fig. 7A

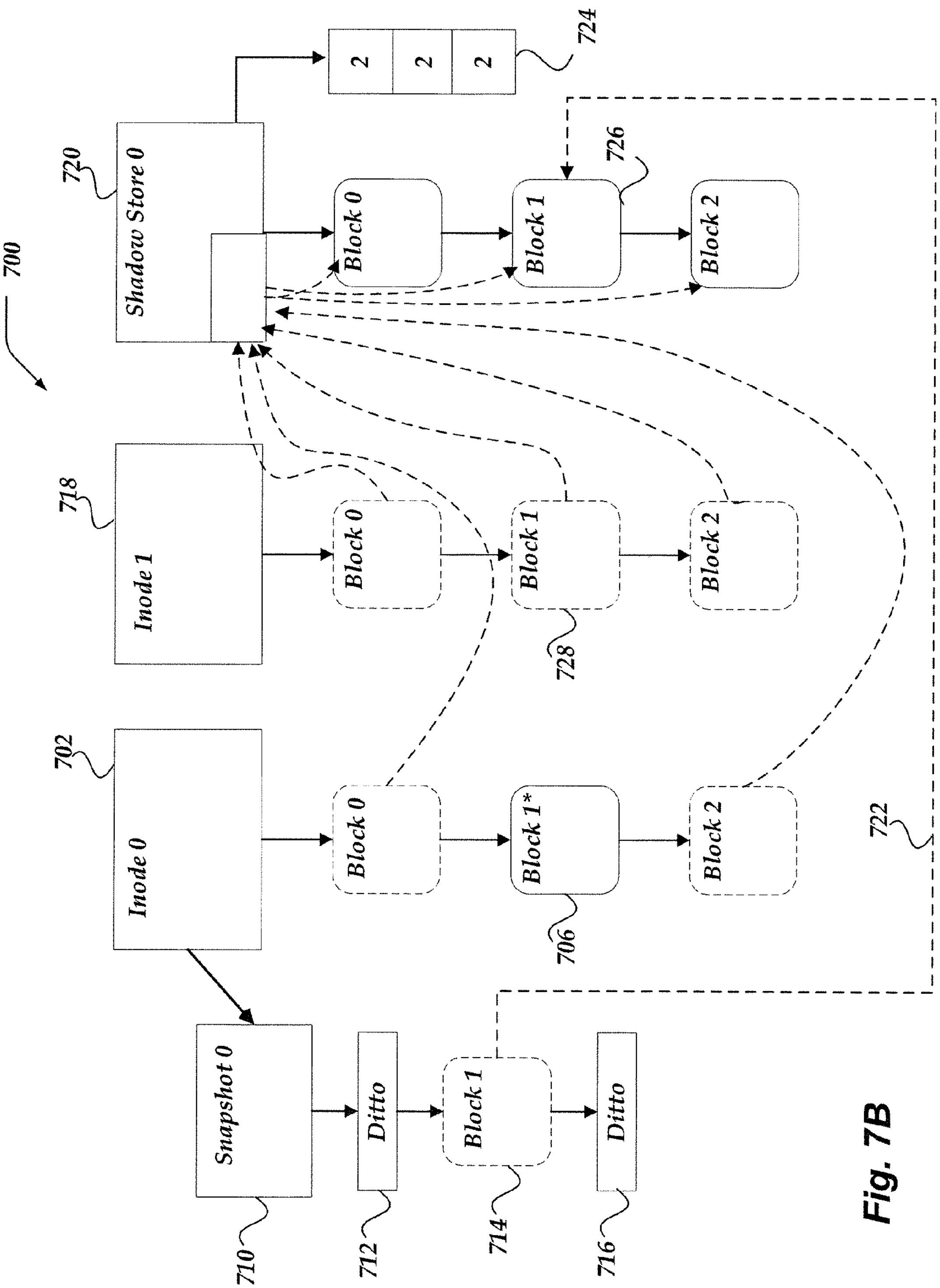

700
Shadow Store 0
720
2
2
2
724
Block 0
Block 1
Block 2
726
Inode 1
718
Block 0
Block 1
Block 2
728
Inode 0
702
Block 0
Block 1*
Block 2
706
722
Snapshot 0
Ditto
Block 1
Ditto
710
712
714
716

Fig. 7B

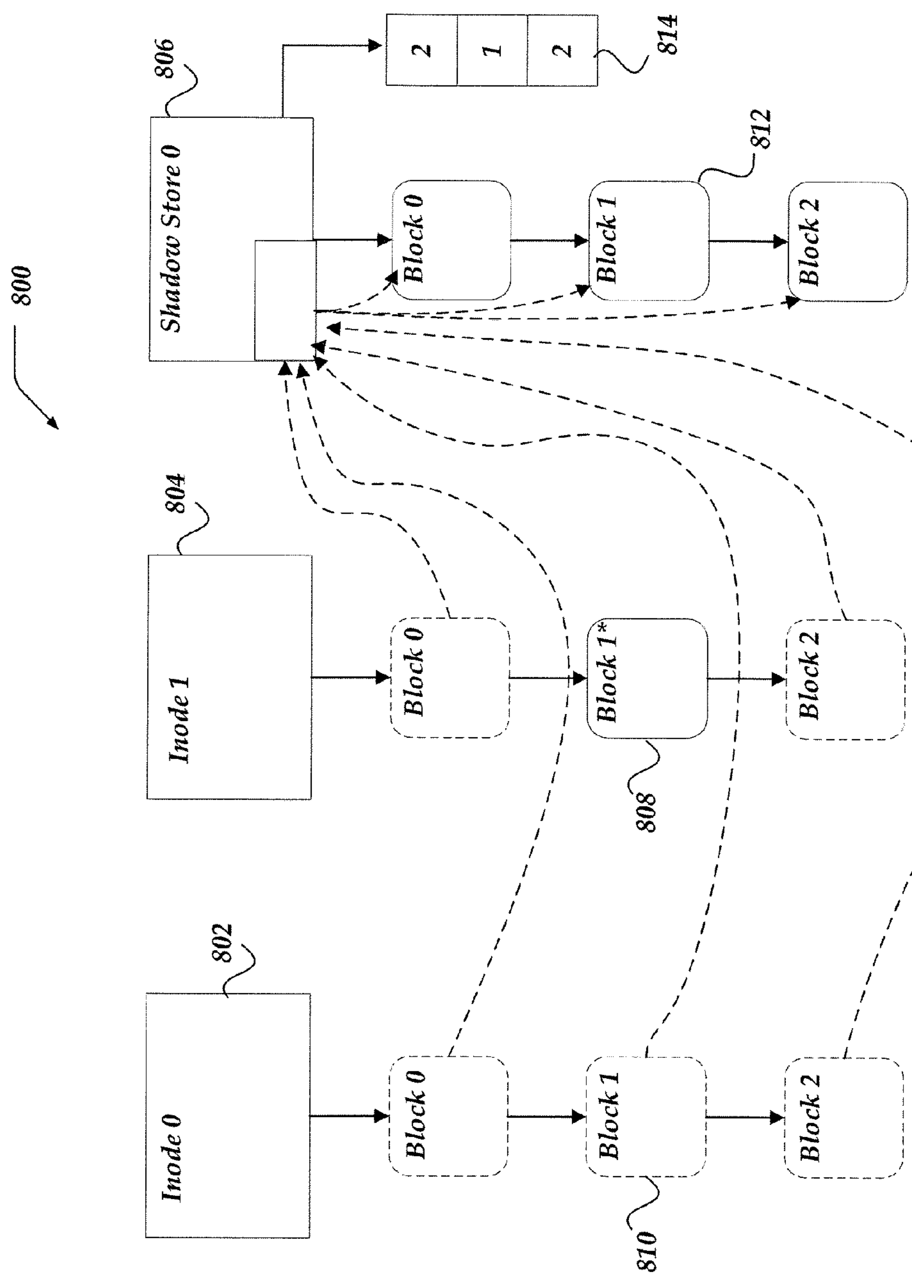

800
806
Shadow Store 0
2
1
2
814
Block 0
Block 1
812
Block 2
804
Inode 1
Block 0
Block 1*
808
Block 2
802
Inode 0
Block 0
Block 1
810
Block 2

Fig. 8

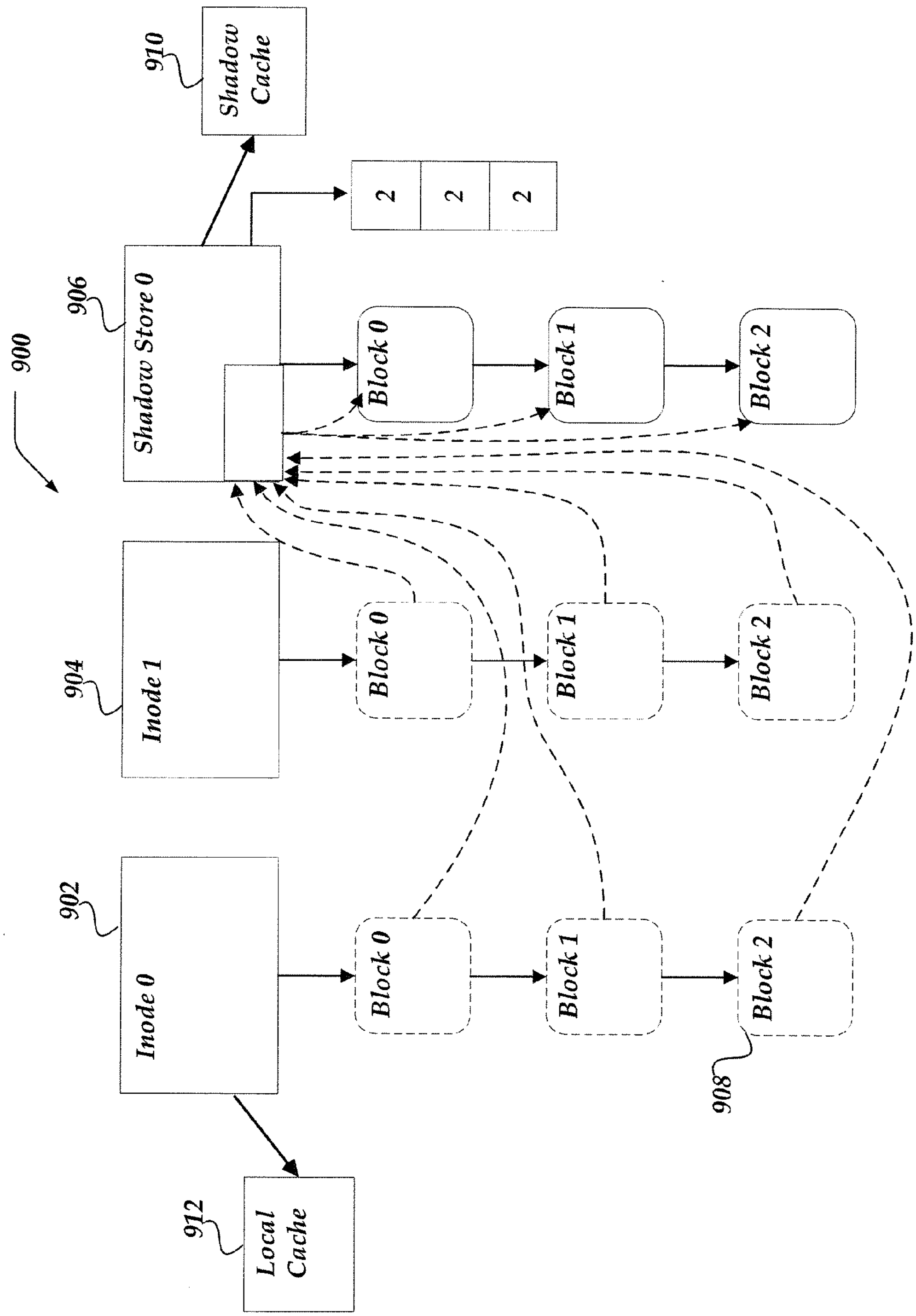

900
910
Shadow Cache
906
Shadow Store 0
2
2
2
Block 0
Block 1
Block 2
904
Inode 1
Block 0
Block 1
Block 2
902
Inode 0
Block 0
Block 1
Block 2
908
912
Local Cache

Fig. 9

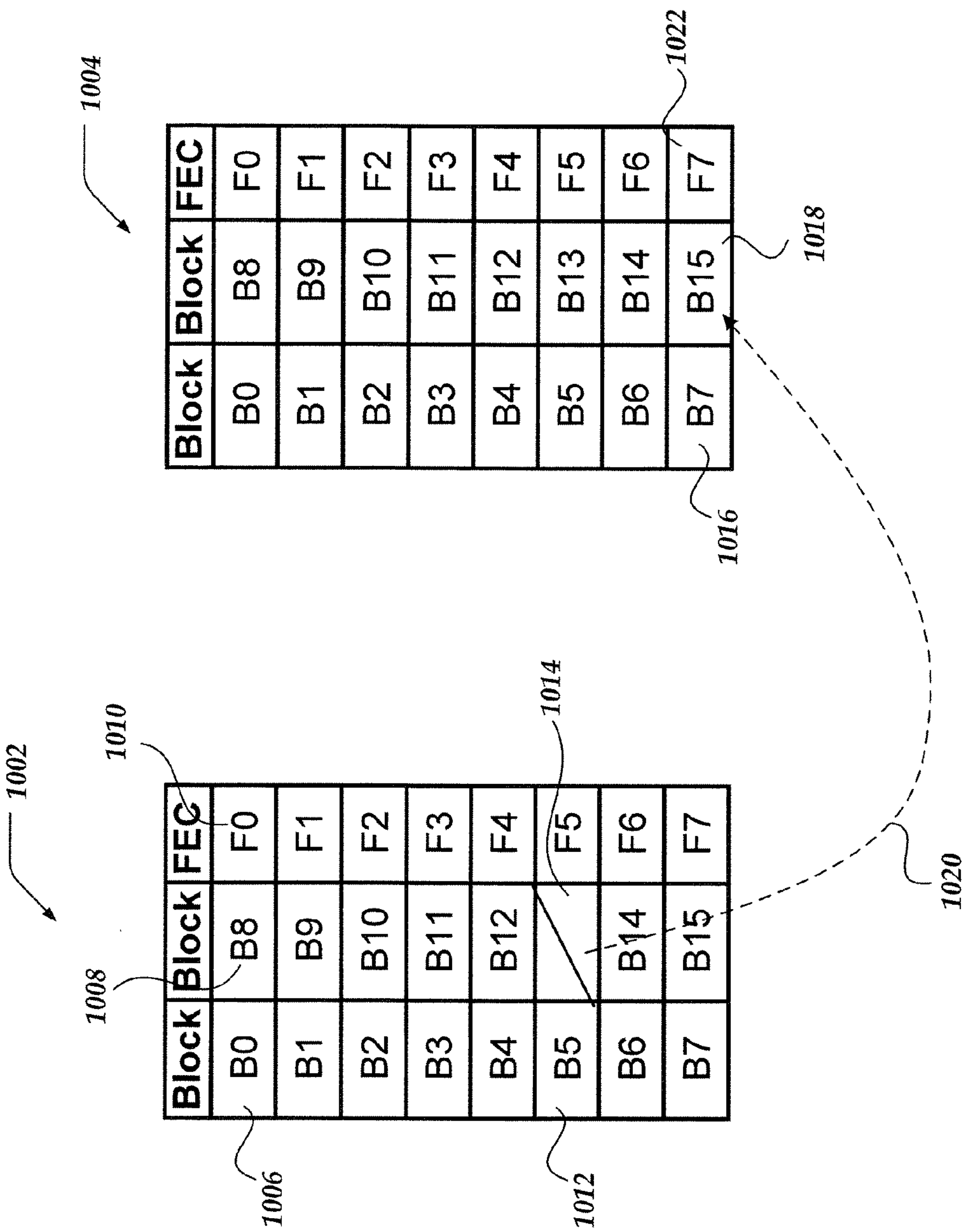

1002
1004
Block
Block
FEC
B0
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B14
B15
F0
F1
F2
F3
F4
F5
F6
F7
B13
1006
1008
1010
1012
1014
1016
1018
1020
1022

Fig. 10

1100

	Delta Read	Delta Write	Shared	Exclusive
Delta Read	yes	yes	yes	no
Delta Write	yes	yes	no	no
Shared	yes	no	yes	no
Exclusive	no	no	no	no

FIG. 11

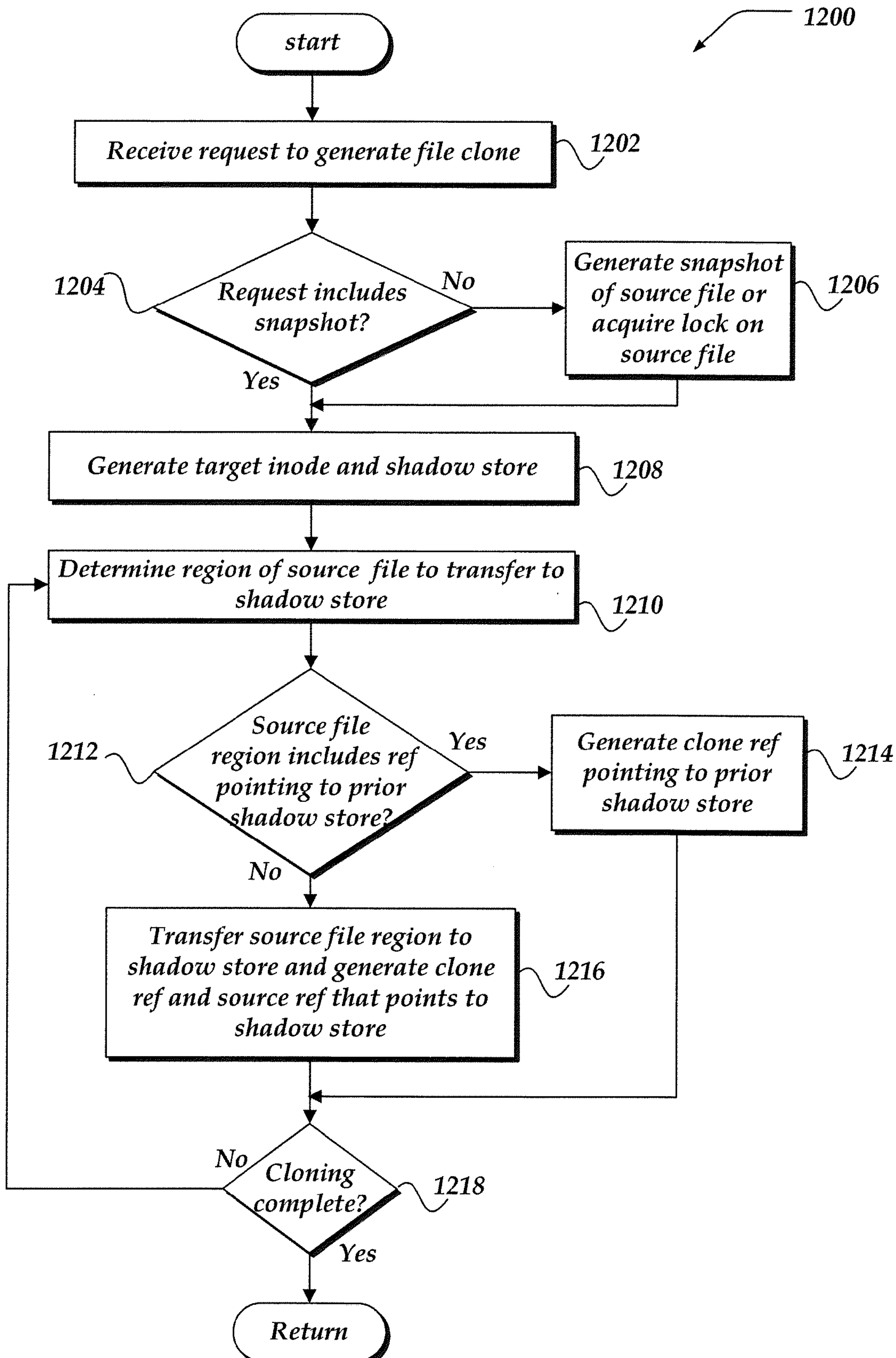

1200
start
Receive request to generate file clone
1202
Request includes snapshot?
1204
No
Generate snapshot of source file or acquire lock on source file
1206
Yes
Generate target inode and shadow store
1208
Determine region of source file to transfer to shadow store
1210
Source file region includes ref pointing to prior shadow store?
1212
Yes
Generate clone ref pointing to prior shadow store
1214
No
Transfer source file region to shadow store and generate clone ref and source ref that points to shadow store
1216
No
Cloning complete?
1218
Yes
Return

Fig. 12

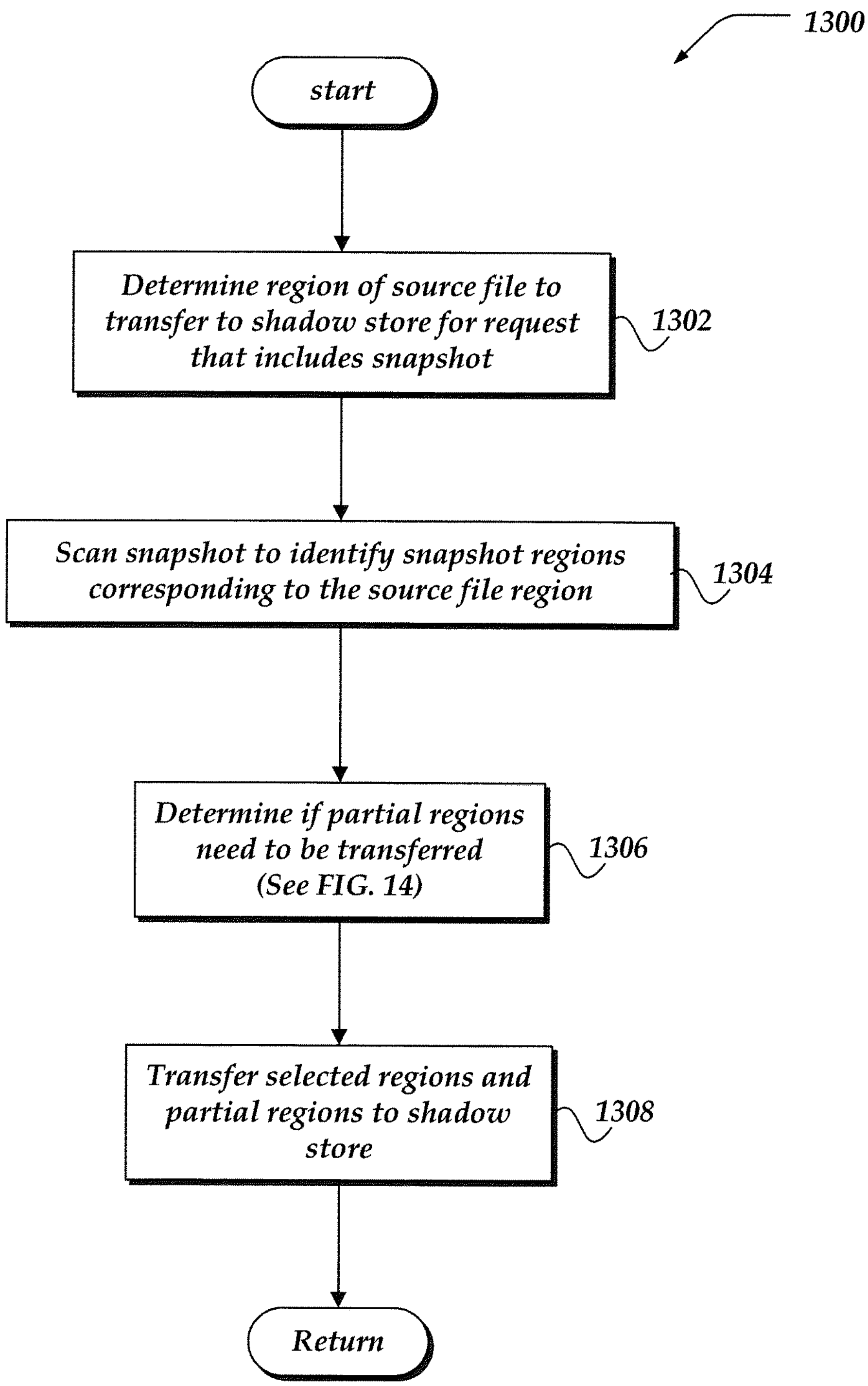

1300
start
Determine region of source file to transfer to shadow store for request that includes snapshot
1302
Scan snapshot to identify snapshot regions corresponding to the source file region
1304
Determine if partial regions need to be transferred (See FIG. 14)
1306
Transfer selected regions and partial regions to shadow store
1308
Return

Fig. 13

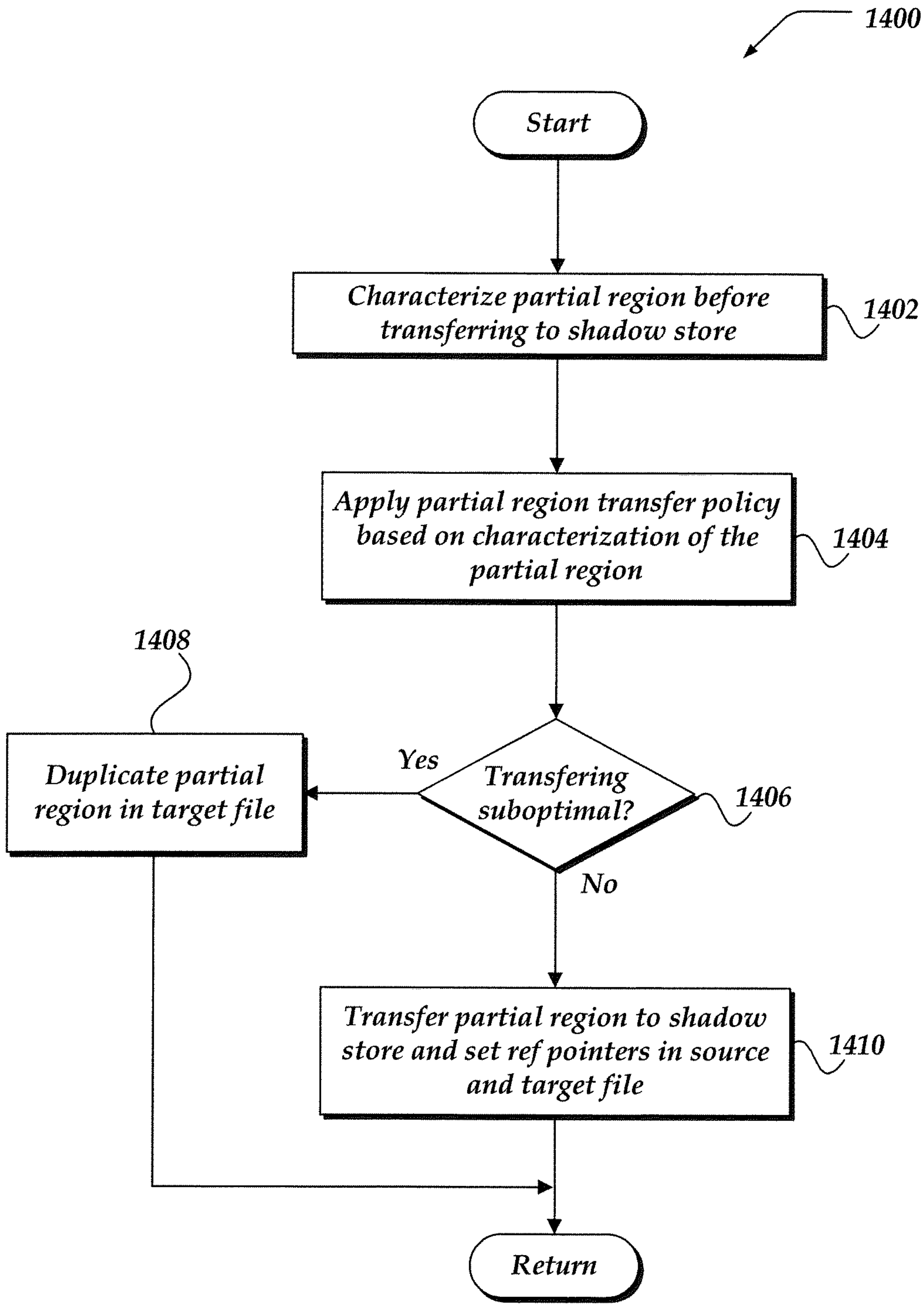

1400
Start
Characterize partial region before transferring to shadow store
1402
Apply partial region transfer policy based on characterization of the partial region
1404
1408
Duplicate partial region in target file
Yes
Transfering suboptimal?
1406
No
Transfer partial region to shadow store and set ref pointers in source and target file
1410
Return

Fig. 14

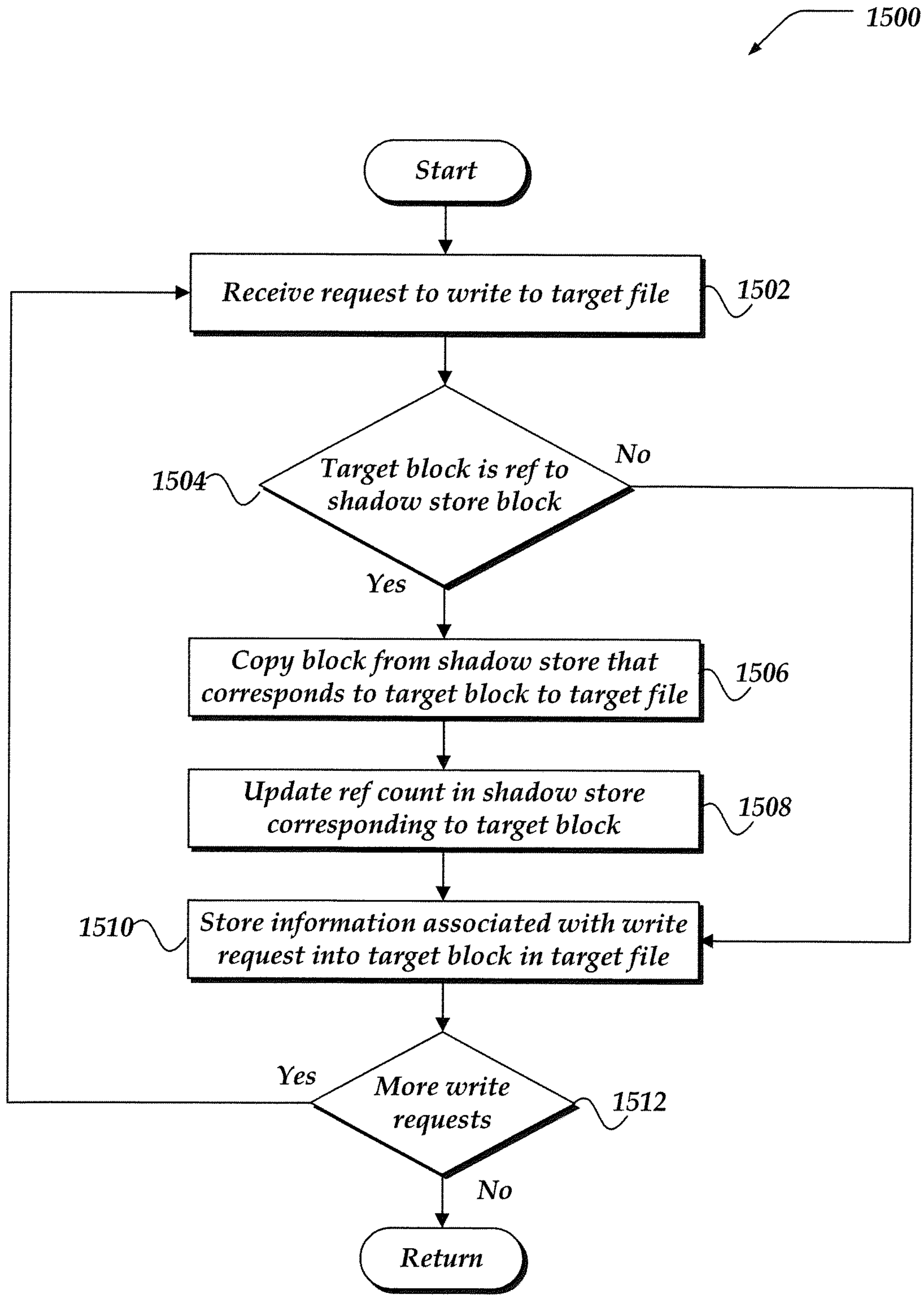

1500
Start
Receive request to write to target file
1502
Target block is ref to shadow store block
1504
No
Yes
Copy block from shadow store that corresponds to target block to target file
1506
Update ref count in shadow store corresponding to target block
1508
Store information associated with write request into target block in target file
1510
Yes
More write requests
1512
No
Return

Fig. 15

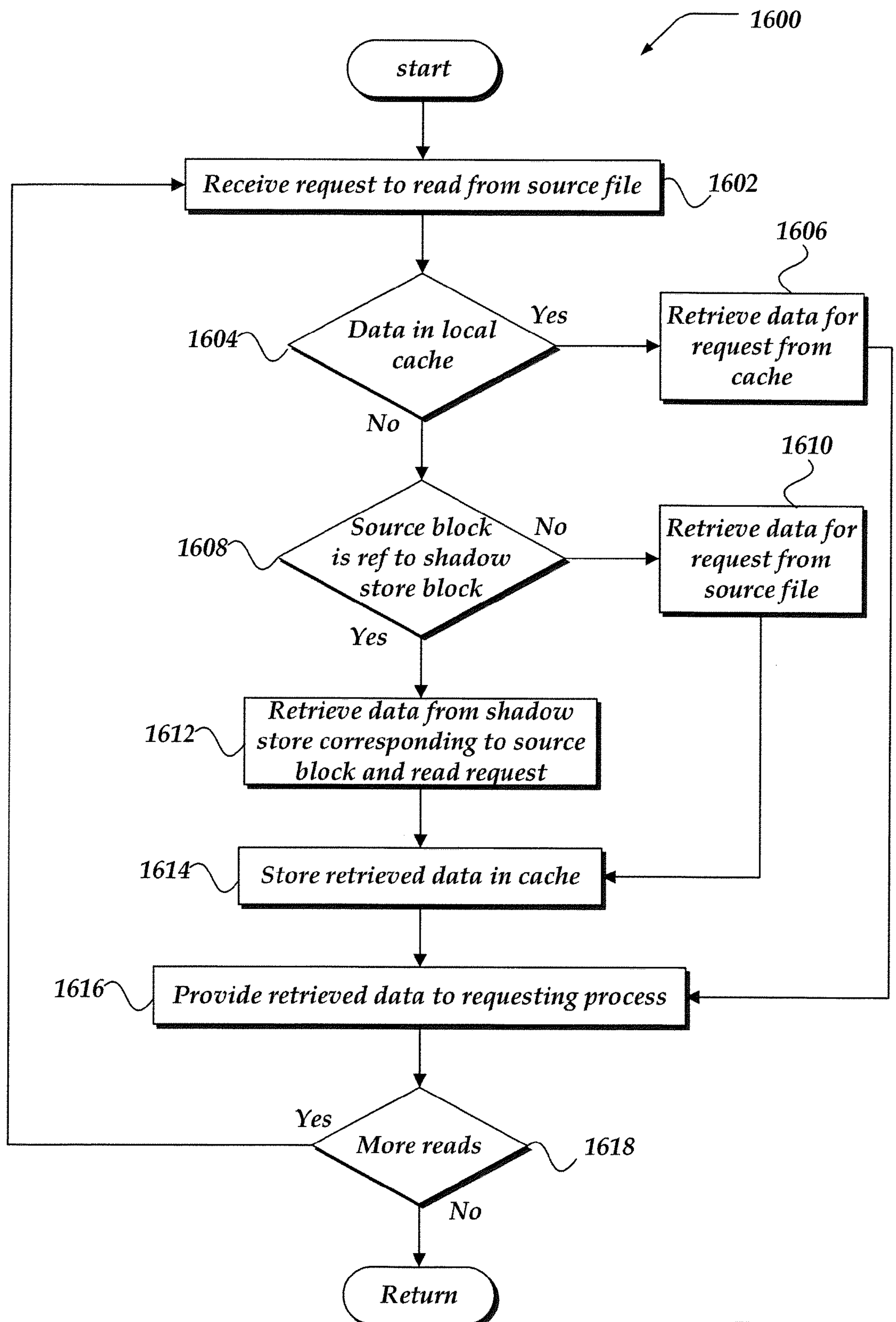

1600
start
Receive request to read from source file
1602
1606
Data in local cache
1604
Yes
Retrieve data for request from cache
No
1610
Source block is ref to shadow store block
1608
No
Retrieve data for request from source file
Yes
Retrieve data from shadow store corresponding to source block and read request
1612
Store retrieved data in cache
1614
Provide retrieved data to requesting process
1616
Yes
More reads
1618
No
Return

Fig. 16

FILE CLONES IN A DISTRIBUTED FILE SYSTEM

TECHNICAL FIELD

The various embodiments relate generally to managing access to files in a file system, and more particularly to, improving performance by enabling improved file copying.

BACKGROUND

High performance computing environments often require distributed high performance file systems. Such file systems may be responsible for storing and managing access to millions of files. In some cases, such file systems may have to provide files for thousands, or even millions of simultaneous users. Additionally, high performance file systems may be required to support very large files.

Accordingly, naively performing standard file operations may unacceptably impact performance. Standard file locking procedures may significantly impact performance and/or negatively effect user experience. Also, naively locking and/or copying very large files may take too long and/or consume too many system resources. Further, naively duplicating large files may unnecessarily consume large amounts of storage space. For example, users often create duplicate files where the duplicate files continue to share the bulk of their content. Thus, naïve duplication may generate unnecessarily duplicative file portions. Consequently, systems that can manage large and/or distributed file systems are the subject of considerable innovation.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments are described with reference to the following drawings. In the drawings, like reference numerals refer to like parts throughout the various figures unless otherwise specified.

For a better understanding, reference will be made to the following Description Of The Various Embodiments, which is to be read in association with the accompanying drawings, wherein:

FIG. **1** illustrates a system environment in which various embodiments may be implemented;

FIG. **2**A shows a schematic drawing of a rack of blade servers;

FIG. **2**B illustrates a schematic embodiment of a blade server that may be included in a rack of blade servers such as that shown in FIG. **2**A;

FIG. **3** shows a schematic embodiment of a mobile device;

FIG. **4** illustrates a schematic embodiment of a network device;

FIGS. **5**A-**5**D illustrate logical schematics showing portions of a file cloning procedure in accordance with at least one of the various embodiments;

FIGS. **6**A-**6**B illustrate logical schematics showing portions of a file cloning procedure if a source file references a prior shadow store in accordance with at least one of the various embodiments;

FIGS. **7**A-**7**B illustrate logical schematics showing portions of a file cloning procedure of a source file having a snapshot in accordance with at least one of the various embodiments;

FIG. **8** illustrates a logical schematic showing portions of a write procedure in accordance with at least one of the various embodiments;

FIG. **9** illustrates a logical schematic showing portions of a read procedure in accordance with at least one of the various embodiments;

FIG. **10** illustrates a data structures associated with protection group error correction that may be used in accordance with at least one of the various embodiments;

FIG. **11** shows an embodiment of file system locks in accordance with the various embodiments;

FIG. **12** shows an overview flowchart for a process for generating a file clone in accordance with at least one of the various embodiments;

FIG. **13** shows a flowchart for a process for determining source file regions for transferring to a shadow store in accordance with at least one of the various embodiments;

FIG. **14** shows a flowchart for a process for transferring partial blocks of a, file to a shadow store in accordance with at least one of the various embodiments;

FIG. **15** shows a flowchart for a process for writing to a file clone in accordance with at least one of the various embodiments; and

FIG. **16** shows a flowchart for a process for reading from a file clone in accordance with at least one of the various embodiments.

DESCRIPTION OF THE VARIOUS EMBODIMENTS

The invention now will be described more fully hereinafter with reference to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific embodiments by which the invention may be practiced. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Among other things, the invention may be embodied as methods or devices. Accordingly, the invention may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The following detailed description is, therefore, not to be taken in a limiting sense.

Throughout the specification and claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise. The phrase "in one embodiment" as used herein does not necessarily refer to the same embodiment, though it may. Furthermore, the phrase "in another embodiment" as used herein does not necessarily refer to a different embodiment, although it may. Thus, as described below, various embodiments may be readily combined, without departing from the scope or spirit of the invention.

In addition, as used herein, the term "or" is an inclusive "or" operator, and is equivalent to the term "and/or," unless the context clearly dictates otherwise. The term "based on" is not exclusive and allows for being based on additional factors not described, unless the context clearly dictates otherwise. In addition, throughout the specification, the meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

Various embodiments now will be described more fully hereinafter with reference to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific exemplary embodiments by which the invention may be practiced. The embodiments may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the embodiments to those skilled in the art. Among other things, the various embodiments may be methods, systems, media or devices. Accordingly, the various embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The following detailed description is, therefore, not to be taken in a limiting sense.

For example embodiments, the following terms are also used herein according to the corresponding meaning, unless the context clearly dictates otherwise.

The terms "snapshot," or "snapshots" as used herein refer to a data structure that maintains a stable image in a well-defined state for one or more files in a file system. Snapshots preserve point-in-time consistent state and/or contents of one or more files. Snapshots may enable the state and/or contents of files to be preserved based on the point-in-time the snapshot was generated. In at least one of the various embodiments, snapshots may be generated on demand or automatically (e.g., event driven and/or timer driven).

In at least one of the various embodiments, if a data block is about to be modified it may be copied from the file to the snapshot to preserve the block. Data blocks in a file that remain unmodified may be absent from the snapshot data structure. Thus, in at least one of the various embodiments, a snapshot may be a sparse copy of the file contents with unmodified data blocks remaining in the file rather in being copied to the snapshot.

The terms "writer," or "writers" as used herein refer to threads, processes, applications, or the like, that may be writing data, or trying to write data, to a file on a file system. Likewise, "reader," or "readers," as used herein refer to threads, processes, applications, or the like, that may be reading, or trying to read data, from a file on a file system. Readers and/or writers may be part of the same process or application, as in the case of threads, or they may be in separate processes or applications. Further, they may be running on the same computing device or on one or more separate computing devices.

The term "inode," as used herein refers to data structures that may store information, or meta-data, about files and folders, such as size, file ownership, access mode (read, write, execute permissions), time and date of creation and modification, file type, or the like. In at least one of the various embodiments, inode data structures may contain one or more references or pointer to the actual data blocks of the contents stored in the file. In at least one of the various embodiments, inodes may be in a known location in a file system. From an inode, a reader or writer may access the contents of the inode and the contents of the file. Some file systems implement inodes using a data structure called an inode. In at least one of the various embodiments, a data structure explicitly named "inode" may be absent, but file systems may have data structures that store data similar to inodes and may provide capabilities similar to inodes as described herein. Also, in at least one of the various embodiments, the inode data may be referred to as stat data, in reference to the stat system call that provides the data to processes.

The term "delta data" as used herein, refers to data elements, fields, or ranges, of a data structure where updates to such data may be recorded in a journaling system rather than being applied directly to actual instance of the data structure.

The term "non-delta data" as used herein, refers to data elements, fields, or ranges, of a data structure where updates to such data may be applied directly to an instance of the data structure rather than recorded as journal deltas.

The term "journal deltas" as used herein, refers to entries or records stored in a journaling system that may record or track changes made to the delta data of a data structure instance.

The term "data block" as used herein refers to file based data structures that may be the basic unit for data contained in a file. One or more data blocks may be associated with an inode or a shadow store using various well-known data structures such as b-trees, linked lists, or the like. In at least one of the various embodiments, data blocks may include meta-data (e.g., one or more pointers) that reference physical blocks on a storage device.

The term "reference block" as used herein refers to a block owned by an inode that serves as an indirect reference to a data block owned by a shadow store. Reference blocks may include a pointer or reference to a data block instead of the data content. Multiple reference blocks (e.g., from separate files) may reference the same shadow store block. In at least one of the various embodiments, reference blocks may be generated from data blocks by changing the meta-data within the block. For example, a data block may include meta-data (e.g., a pointer) that points to a physical block on a storage device. The data block may be converted to a reference block by changing the meta-data pointer to point to logical blocks that may be in a shadow store. The data block may be considered replaced by a reference block if the meta-data in the block is modified to point to a shadow store block.

The term "data region" as used herein refers to one or more data/reference blocks treated as a group. In some embodiments it may be advantageous to group blocks into data regions if transferring and/or processing data. In at least one of the various embodiments, a region may include a mix of data blocks and/or reference blocks. In some cases a data region may be defined based on address ranges within a file. For example, a data region may be defined as blocks 0 through 20 in a file and it may include a combination of data blocks or reference blocks.

The terms "partial data region," or "partial data block" as used herein refer to an amount of data less than the capacity of a data block. For example, in at least one of the various embodiments, if a file system is configured such that data blocks have a capacity of 64 kilobytes, a portion of data that is 24 kilobytes may be considered a partial data block.

The term "protection group" as used herein refers to a collection of data blocks arranged to support error correction and error validation techniques such as forward error correction. Protection groups often may be arranged to include one or more data blocks and one or more error correction blocks. In at least one of the various embodiments, if data blocks are damaged or lost, in some cases, the error correction blocks in a protection group may be used to recover the damaged or lost data.

The term "shadow store" as used herein refers to a file-based data structure that includes one or more data blocks that may be referenced by one or more reference blocks. In at least one of the various embodiments, shadow stores may be indirectly accessed by readers or writers. Data in a shadow store is accessed by way of dereferencing the pointer information that may be in reference blocks.

The term "shadow store block," or "shadow store region" as used herein refer data blocks or data regions that may be associated with a shadow store. Generally, they are the same as data blocks and data regions except rather than associated with file inodes they are associated with shadow stores. This terminology is useful for distinguishing between data blocks owned by inodes and data blocks owned by a shadow store.

Briefly stated, various embodiments are directed towards cloning files in a distributed file system. In response to a request to create one or more file clones, a file cloning application may be employed to generate one or more file clones based on a source file. The file cloning application may generate a new inode for each new file clone and at least one new shadow store. Data blocks from the source file may be transferred to the shadow store. The transferred data blocks may be replaced with reference blocks that point to the data blocks that were transferred to the shadow store. Likewise, additional reference blocks pointing to data blocks in the shadow store may be generated and associated with the new file clone inodes. Further, the shadow store may maintain reference counters that track the number of reference blocks pointing to each shadow store block.

Also, in at least one of the various embodiments, file clones may be generated based on a point-in-time snapshot of the source file. If the source file data blocks have been modified since the taking of the snapshot, data blocks from the snapshot corresponding to the modified data blocks in the source file may be transferred to the shadow store. If a source file data block may be unmodified since the taking of the snapshot, the data block may be transferred directly from the source file to the shadow store.

In at least one of the various embodiments, if the target address of a write operation directed at a file resolves to a reference block, the reference block in the file may be replaced by copying the corresponding shadow store block from the shadow store before completing the write operation. As reference blocks are replaced by data blocks, the corresponding reference counters in the shadow store may be decremented.

In at least one of the various embodiments, if the reference count for a data block is reduced to zero, the corresponding shadow store block may be discarded. In at least one of the various embodiments, a scheduled process may be configure to sweep through the file system and delete discarded shadow store blocks.

In at least one of the various embodiments, if a address of a data read directed at a file resolves to a reference block, the file system may dereference the pointers and/or references included in the reference block to retrieve the requested data from the corresponding shadow store block.

In at least one of the various embodiments, file clones may be generated from source files that include reference blocks pointing to a shadow store from a previous file cloning operation. Thus, in at least one of the various embodiments, the source file may include reference blocks pointing to shadow store block from a shadow store generated during the previous cloning. For preexisting reference blocks found in the source file during cloning, the new clone files may receive corresponding reference blocks that point to the old shadow store. This may result in file clones that include reference blocks pointing to multiple shadow stores.

In at least one of the various embodiments, one or more local in-memory read caches may be generated at a file inode to reduce latency for subsequent reads of the same data. Each inode for each file clone may have its own local in-memory read cache. Accordingly, some data regions may be cached multiple times. Also, in-memory read caches may be generated local the shadow-store. In at least one of the various embodiments, in-memory caches may be generated on the computing device nodes that may comprise a distributed file system.

Furthermore, in at least one of the various embodiments, a file cloning application may determine that partial data blocks may be copied directly to the file clones rather than transferring to the shadow store and generating reference blocks in the file clones.

Illustrative Operating Environment

FIG. **1** shows components of an environment in which various embodiments may be practiced. Not all of the components may be required to practice the various embodiments, and variations in the arrangement and type of the components may be made without departing from the spirit or scope of the various embodiments.

In at least one embodiment, cloud network **102** enables one or more network services for a user based on the operation of corresponding arrangements **104** and **106** of virtually any type of networked computing device. As shown, the networked computing devices may include server network device **112**, host network device **114**, enclosure of blade servers **110**, enclosure of server computers **116**, super computer network device **118**, and the like. Although not shown, one or more mobile devices may be included in cloud network **102** in one or more arrangements to provide one or more network services to a user. Also, these arrangements of networked computing devices may or may not be mutually exclusive of each other.

Additionally, the user may employ a plurality of virtually any type of wired or wireless networked computing devices to communicate with cloud network **102** and access at least one of the network services enabled by one or more of arrangements **104** and **106**. These networked computing devices may include tablet mobile device **122**, handheld mobile device **124**, wearable mobile device **126**, desktop network device **120**, and the like. Although not shown, in various embodiments, the user may also employ notebook computers, desktop computers, microprocessor-based or programmable consumer electronics, network appliances, mobile telephones, smart telephones, pagers, radio frequency (RF) devices, infrared (IR) devices, Personal Digital Assistants (PDAs), televisions, integrated devices combining at least one of the preceding devices, and the like.

One embodiment of a mobile device is described in more detail below in conjunction with FIG. **3**. Generally, mobile devices may include virtually any substantially portable networked computing device capable of communicating over a wired, wireless, or some combination of wired and wireless network.

In various embodiments, network **102** may employ virtually any form of communication technology and topology. For example, network **102** can include local area networks Personal Area Networks (PANs), (LANs), Campus Area Networks (CANs), Metropolitan Area Networks (MANs) Wide Area Networks (WANs), direct communication connections, and the like, or any combination thereof. On an interconnected set of LANs, including those based on differing architectures and protocols, a router acts as a link between LANs, enabling messages to be sent from one to another. In addition, communication links within networks may include virtually any type of link, e.g., twisted wire pair lines, optical fibers, open air lasers or coaxial cable, plain old telephone service (POTS), wave guides, acoustic, full or fractional dedicated digital communication lines including T**1**, T**2**, T**3**, and T**4**, and/or other carrier and other wired media and wireless media. These carrier mechanisms may include E-carriers, Integrated Services Digital Networks (ISDNs), universal serial bus (USB) ports, Firewire ports, Thunderbolt ports, Digital Subscriber Lines (DSLs), wireless links including satellite links, or other communications links known to those skilled in the art. Moreover, these communication links may further employ any of a variety of digital signaling technologies, including without limit, for example, DS-0, DS-1, DS-2, DS-3, DS-4, OC-3, OC-12, OC-48, or the like. Furthermore, remotely located computing devices could be remotely connected to networks via a modem and a temporary communication link. In essence, network **102** may include virtually any communication technology by which information may travel between computing devices. Additionally, in the various embodiments, the communicated information may include virtually any kind of information including, but not limited to processor-readable instructions, data structures, program modules, applications, raw data, control data, archived data, video data, voice data, image data, text data, and the like.

Network **102** may be partially or entirely embodied by one or more wireless networks. A wireless network may include any of a variety of wireless sub-networks that may further overlay stand-alone ad-hoc networks, and the like. Such sub-networks may include mesh networks, Wireless LAN (WLAN) networks, Wireless Router (WR) mesh, cellular networks, pico networks, PANs, Open Air Laser networks, Microwave networks, and the like. Network **102** may further include an autonomous system of intermediate network devices such as terminals, gateways, routers, switches, firewalls, load balancers, and the like, which are coupled to wired and/or wireless communication links. These autonomous devices may be operable to move freely and randomly and organize themselves arbitrarily, such that the topology of network **102** may change rapidly.

Network **102** may further employ a plurality of wired and wireless access technologies, e.g., 2nd (2G), 3rd (3G), 4th (4G), 5^{th} (5G) generation wireless access technologies, and the like, for mobile devices. These wired and wireless access technologies may also include Global System for Mobile communication (GSM), General Packet Radio. Services (GPRS), Enhanced Data GSM Environment (EDGE), Code Division Multiple Access (CDMA), Wideband Code Division Multiple Access (WCDMA), Long Term Evolution Advanced (LTE), Universal Mobile Telecommunications System (UMTS), Orthogonal frequency-division multiplexing (OFDM), Wideband Code Division Multiple Access (W-CDMA), Code Division Multiple Access 2000 (CDMA2000), Evolution-Data Optimized (EV-DO), High-Speed Downlink Packet Access (HSDPA), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), ultra wide band (UWB), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), any portion of the Open Systems Interconnection (OSI) model protocols, Short Message Service (SMS), Multimedia Messaging Service (MMS), Web Access Protocol (WAP), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), or any of a variety of other wireless or wired communication protocols. In one non-limiting example, network **102** may enable a mobile device to wirelessly access a network service through a combination of several radio network access technologies such as GSM, EDGE, SMS, HSDPA, LTE and the like.

Enclosure of Blade Servers

FIG. **2**A shows one embodiment of an enclosure of blade servers **200**, which are also illustrated in FIG. **1**. Enclosure of blade servers **200** may include many more or fewer components than those shown in FIG. **2**A. However, the components shown are sufficient to disclose an illustrative embodiment. Generally, a blade server is a stripped down server computing device with a modular design optimized to minimize the use of physical space and energy. A blade enclosure can include several blade servers and provide each with power, cooling, network interfaces, input/output interfaces, and resource management. Although not shown, an enclosure of server computers typically includes several computers that merely require a network connection and a power cord connection to operate. Each server computer often includes redundant components for power and interfaces.

As shown in the figure, enclosure **200** contains power supply **204**, and input/output interface **206**, rack logic **208**, several blade servers **210**, **212**, **214**, and **216**, and backplane **202**. Power supply **204** provides power to each component and blade server within the enclosure. The input/output interface **206** provides internal and external communication for components and blade servers within the enclosure. Backplane **208** can enable passive and active communication of power, logic, input signals, and output signals for each blade server.

Illustrative Blade Server

FIG. **2**B illustrates an illustrative embodiment of blade server **250**, which may include many more or fewer components than those shown. As shown in FIG. **2**A, a plurality of blade servers may be included in one enclosure that shares resources provided by the enclosure to reduce size, power, and cost.

Blade server **250** includes processor **252** which communicates with memory **256** via bus **254**. Blade server **250** also includes input/output interface **290**, processor-readable stationary storage device **292**, and processor-readable removable storage device **294**. Input/output interface **290** can enable blade server **250** to communicate with other blade servers, mobile devices, network devices, and the like. Interface **190** may provide wireless and/or wired communication links for blade server. Processor-readable stationary storage device **292** may include devices such as an electromagnetic storage device (hard disk), solid state hard disk (SSD), hybrid of both an SSD and a hard disk, and the like. Also, processor-readable removable storage device **294** enables processor **252** to read non-transitive storage media for storing and accessing processor-readable instructions, modules, data structures, and other forms of data. The non-transitive storage media may include Flash drives, tape media, floppy media, and the like.

Memory **256** may include Random Access Memory (RAM), Read-Only Memory (ROM), hybrid of RAM and ROM, and the like. As shown, memory **256** includes operating system **258** and basic input/output system (BIOS) **260** for enabling the operation of blade server **250**. In various embodiments, a general-purpose operating system may be employed such as a version of UNIX, or LINUX™, or a specialized server operating system such as Microsoft's Windows Server™ and Apple Computer's IoS Server™.

Memory **256** further includes one or more data storage **270**, which can be utilized by blade server **250** to store, among other things, applications **280** and/or other data. Data stores **270** may include program code, data, algorithms, and the like, for use by processor **252** to execute and perform actions. In one embodiment, at least some of data store **270** might also be stored on another component of blade server **250**, including, but not limited to, processor-readable removable storage device **294**, processor-readable stationary storage device **292**, or any other processor-readable storage device (not shown). Data storage **270** may include, for example, file stores **274**, and shadow stores **276**.

Applications **280** may include processor executable instructions which, when executed by blade server **250**, transmit, receive, and/or otherwise process messages, audio, video, and enable communication with other networked computing devices. Examples of application programs include database servers, file servers, calendars, transcoders, and so forth. Applications **280** may include, for example, file cloning application **282**, and file system application **284**.

Human interface components (not pictured), may be remotely associated with blade server **250**, which can enable remote input to and/or output from blade server **250**. For example, information to a display or from a keyboard can be routed through the input/output interface **290** to appropriate peripheral human interface components that are remotely located. Examples of peripheral human interface components include, but are not limited to, an audio interface, a display, keypad, pointing device, touch interface, and the like.

Illustrative Mobile Device

FIG. **3** shows one embodiment of mobile device **300** that may include many more or less components than those shown. Mobile device **300** may represent, for example, at least one embodiment of mobile devices shown in FIG. **1**.

Mobile device **300** includes processor **302** in communication with memory **304** via bus **328**. Mobile device **300** also includes power supply **330**, network interface **332**, audio interface **356**, display **350**, keypad **352**, illuminator **354**, video interface **342**, input/output interface **338**, haptic interface **364**, global positioning systems (GPS) receiver **358**, Open air gesture interface **360**, temperature interface **362**, camera(s) **340**, projector **346**, pointing device interface **366**, processor-readable stationary storage device **334**, and processor-readable removable storage device **336**. Power supply **330** provides power to mobile device **300**. A rechargeable or non-rechargeable battery may be used to provide power. The power may also be provided by an external power source, such as an AC adapter or a powered docking cradle that supplements and/or recharges the battery. And in one embodiment, although not shown, a gyroscope may be employed within mobile device **300** to measuring and/or maintaining an orientation of mobile device **300**.

Mobile device **300** may optionally communicate with a base station (not shown), or directly with another computing device. Network interface **332** includes circuitry for coupling mobile device **300** to one or more networks, and is constructed for use with one or more communication protocols and technologies including, but not limited to, protocols and technologies that implement any portion of the Open Systems Interconnection (OSI) model for mobile communication (GSM), code division multiple access (CDMA), time division multiple access (TDMA), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), Short Message Service (SMS), Multimedia Messaging Service (MMS), general packet radio service (GPRS), Web Access Protocol (WAP), ultra wide band (UWB), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), General Packet Radio Services (GPRS), Enhanced Data GSM Environment (EDGE), Wideband Code Division Multiple Access (WCDMA), Long Term Evolution Advanced (LTE), Universal Mobile Telecommunications System (UMTS), Orthogonal frequency-division multiplexing (OFDM), Code Division Multiple Access 2000 (CDMA2000), Evolution-Data Optimized (EV-DO), High-Speed Downlink Packet Access (HSDPA), or any of a variety of other wireless communication protocols. Network interface **332** is sometimes known as a transceiver, transceiving device, or network interface card (NIC).

Audio interface **356** is arranged to produce and receive audio signals such as the sound of a human voice. For example, audio interface **356** may be coupled to a speaker and microphone (not shown) to enable telecommunication with others and/or generate an audio acknowledgement for some action. A microphone in audio interface **356** can also be used for input to or control of mobile device **300**, e.g., using voice recognition, detecting touch based on sound, and the like.

Display **350** may be a liquid crystal display (LCD), gas plasma, electronic ink, light emitting diode (LED), Organic LED (OLED) or any other type of light reflective or light transmissive display that can be used with a computing device. Display **350** may also include a touch interface **344** arranged to receive input from an object such as a stylus or a digit from a human hand, and may use resistive, capacitive, surface acoustic wave (SAW), infrared, radar, or other technologies to sense touch and/or gestures. Projector **346** may be a remote handheld projector or an integrated projector that is capable of projecting an image on a remote wall or any other reflective object such as a remote screen.

Video interface **342** may be arranged to capture video images, such as a still photo, a video segment, an infrared video, or the like. For example, video interface **342** may be coupled to a digital video camera, a web-camera, or the like. Video interface **342** may comprise a lens, an image sensor, and other electronics. Image sensors may include a complementary metal-oxide-semiconductor (CMOS) integrated circuit, charge-coupled device (CCD), or any other integrated circuit for sensing light.

Keypad **352** may comprise any input device arranged to receive input from a user. For example, keypad **352** may include a push button numeric dial, or a keyboard. Keypad **352** may also include command buttons that are associated with selecting and sending images. Illuminator **354** may provide a status indication and/or provide light. Illuminator **354** may remain active for specific periods of time or in response to events. For example, when illuminator **354** is active, it may backlight the buttons on keypad **352** and stay on while the mobile device is powered. Also, illuminator **354** may backlight these buttons in various patterns when particular actions are performed, such as dialing another mobile device. Illuminator **354** may also cause light sources positioned within a transparent or translucent case of the mobile device to illuminate in response to actions.

Mobile device **300** also comprises input/output interface **338** for communicating with external peripheral devices or other computing devices such as other mobile devices and network devices. The peripheral devices may include an audio headset, display screen glasses, remote speaker system, remote speaker and microphone system, and the like. Input/output interface **338** can utilize one or more technologies, such as Universal Serial Bus (USB), Infrared, WiFi, WiMax, Bluetooth™, and the like. Haptic interface **364** is arranged to provide tactile feedback to a user of the mobile device. For example, the haptic interface **364** may be employed to vibrate mobile device **300** in a particular way when another user of a computing device is calling. Temperature interface **362** may be used to provide a temperature measurement input and/or a temperature changing output to a user of mobile device **300**. Open air gesture interface **360** may sense physical gestures of a user of mobile device **300**, for example, by using single or stereo video cameras, radar, a gyroscopic sensor inside a device held or worn by the user, or the like. Camera **340** may be used to track physical eye movements of a user of mobile device **300**.

GPS transceiver **358** can determine the physical coordinates of mobile device **300** on the surface of the Earth, which typically outputs a location as latitude and longitude values. GPS transceiver **358** can also employ other geo-positioning mechanisms, including, but not limited to, triangulation, assisted GPS (AGPS), Enhanced Observed Time Difference (E-OTD), Cell Identifier (CI), Service Area Identifier (SAI), Enhanced Timing Advance (ETA), Base Station Subsystem (BSS), or the like, to further determine the physical location of mobile device **300** on the surface of the Earth. It is understood that under different conditions, GPS transceiver **358** can determine a physical location for mobile device **300**. In at least one embodiment, however, mobile device **300** may, through other components, provide other information that may be employed to determine a physical location of the device, including for example, a Media Access Control (MAC) address, IP address, and the like.

Human interface components can be peripheral devices that are physically separate from mobile device **300**, allowing for remote input and/or output to mobile device **300**. For example, information routed as described here through human interface components such as display **350** or keyboard **352** can instead be routed through network interface **332** to appropriate human interface components located remotely. Examples of human interface peripheral components that may be remote include, but are not limited to, audio devices, pointing devices, keypads, displays, cameras, projectors, and the like. These peripheral components may communicate over a Pico Network such as Bluetooth™, Zigbee™ and the like. One non-limiting example of a mobile device with such peripheral human interface components is a wearable computing device, which might include a remote pico projector along with one or more cameras that remotely communicate with a separately located mobile device to sense a user's gestures toward portions of an image projected by the pico projector onto a reflected surface such as a wall or the user's hand.

A mobile device may include a browser application that is configured to receive and to send web pages, web-based messages, graphics, text, multimedia, and the like. The mobile device's browser application may employ virtually any programming language, including a wireless application protocol messages (WAP), and the like. In at least one embodiment, the browser application is enabled to employ Handheld Device Markup Language (HDML), Wireless Markup Language (WML), WMLScript, JavaScript, Standard Generalized Markup Language (SGML), HyperText Markup Language (HTML), eXtensible Markup Language (XML), HTML5, and the like.

Memory **304** may include Random Access Memory (RAM), Read-Only Memory (ROM), and/or other types of memory. Memory **304** illustrates an example of computer-readable storage media (devices) for storage of information such as computer-readable instructions, data structures, program modules or other data. Memory **304** stores a basic input/output system (BIOS) **308** for controlling low-level operation of mobile device **300**. The memory also stores an operating system **306** for controlling the operation of mobile device **300**. It will be appreciated that this component may include a general-purpose operating system such as a version of UNIX, or LINUX™, or a specialized mobile computer communication operating system such as Windows Mobile™, or the Symbian® operating system. The operating system may include, or interface with a Java virtual machine module that enables control of hardware components and/or operating system operations via Java application programs.

Memory **304** further includes one or more data storage **310**, which can be utilized by mobile device **300** to store, among other things, applications **320** and/or other data. For example, data storage **310** may also be employed to store information that describes various capabilities of mobile device **300**. The information may then be provided to another device based on any of a variety of events, including being sent as part of a header during a communication, sent upon request, or the like. Data storage **310** may also be employed to store social networking information including address books, buddy lists, aliases, user profile information, or the like. Data storage **310** may further include program code, data, algorithms, and the like, for use by a processor, such as processor **302** to execute and perform actions. In one embodiment, at least some of data storage **310** might also be stored on another component of mobile device **300**, including, but not limited to, non-transitory processor-readable removable storage device **336**, processor-readable stationary storage device **334**, or even external to the mobile device. Data storage **310** may include, for example, file data **314**.

Applications **320** may include computer executable instructions which, when executed by mobile device **300**, transmit, receive, and/or otherwise process instructions and data. Applications **320** may include, for example, file clone application **322**, and file system application **324**. Other examples of application programs include calendars, search programs, email client applications, IM applications, SMS applications, Voice Over Internet Protocol (VOIP) applications, contact managers, task managers, transcoders, database programs, word processing programs, security applications, spreadsheet programs, games, search programs, and so forth.

Illustrative Network Device

FIG. **4** shows one embodiment of network device **400** that may be included in a system implementing the invention. Network device **400** may include many more or less components than those shown in FIG. **4**. However, the components shown are sufficient to disclose an illustrative embodiment for practicing the present invention. Network device **400** may represent, for example, one embodiment of at least one of network device **112**, **114**, or **120** of FIG. **1**.

As shown in the figure, network device **400** includes a processor **402** in communication with a memory **404** via a bus **428**. Network device **400** also includes a power supply **430**, network interface **432**, audio interface **456**, display **450**, keyboard **452**, input/output interface **438**, processor-readable stationary storage device **434**, and processor-readable removable storage device **436**. Power supply **430** provides power to network device **400**.

Network interface **432** includes circuitry for coupling network device **400** to one or more networks, and is constructed for use with one or more communication protocols and technologies including, but not limited to, protocols and technologies that implement any portion of the Open Systems Interconnection model (OSI model), global system for mobile communication (GSM), code division multiple access (CDMA), time division multiple access (TDMA), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), Short Message Service (SMS), Multimedia Messaging Service (MMS), general packet radio service (GPRS), WAP, ultra wide band (UWB), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), or any of a variety of other wired and wireless communication protocols. Network interface **432** is sometimes known as a transceiver, transceiving device, or network interface card (NIC). Network device **400** may optionally communicate with a base station (not shown), or directly with another computing device.

Audio interface **456** is arranged to produce and receive audio signals such as the sound of a human voice. For example, audio interface **456** may be coupled to a speaker and microphone (not shown) to enable telecommunication with others and/or generate an audio acknowledgement for some action. A microphone in audio interface **456** can also be used for input to or control of network device **400**, for example, using voice recognition.

Display **450** may be a liquid crystal display (LCD), gas plasma, electronic ink, light emitting diode (LED), Organic

LED (OLED) or any other type of light reflective or light transmissive display that can be used with a computing device. Display **450** may be a handheld projector or pico projector capable of projecting an image on a wall or other object.

Network device **400** also may also comprise input/output interface **438** for communicating with external devices not shown in FIG. **4**. Input/output interface **438** can utilize one or more wired or wireless communication technologies, such as USB™, Firewire™, WiFi, WiMax, Thunderbolt™, Infrared, Bluetooth™, Zigbee™, serial port, parallel port, and the like.

Human interface components can be physically separate from network device **400**, allowing for remote input and/or output to network device **400**. For example, information routed as described here through human interface components such as display **450** or keyboard **452** can instead be routed through the network interface **432** to appropriate human interface components located elsewhere on the network. Human interface components include any component that allows the computer to take input from, or send output to, a human user of a computer.

Memory **404** may include Random Access Memory (RAM), Read-Only Memory (ROM), and/or other types of memory. Memory **404** illustrates an example of computer-readable storage media (devices) for storage of information such as computer-readable instructions, data structures, program modules or other data. Memory **404** stores a basic input/output system (BIOS) **408** for controlling low-level operation of network device **400**. The memory also stores an operating system **406** for controlling the operation of network device **400**. It will be appreciated that this component may include a general-purpose operating system such as a version of UNIX, or LINUX™, or a specialized operating system such as Microsoft Corporation's Windows® operating system, or the Apple Corporation's IOs® operating system. The operating system may include, or interface with a Java virtual machine module that enables control of hardware components and/or operating system operations via Java application programs.

Memory **404** further includes one or more data storage **410**, which can be utilized by network device **400** to store, among other things, applications **420** and/or other data. For example, data storage **410** may also be employed to store information that describes various capabilities of network device **400**. The information may then be provided to another device based on any of a variety of events, including being sent as part of a header during a communication, sent upon request, or the like. Data storage **410** may also be employed to store social networking information including address books, buddy lists, aliases, user profile information, or the like. Data stores **410** may further include program code, data, algorithms, and the like, for use by a processor, such as processor **402** to execute and perform actions. In one embodiment, at least some of data store **410** might also be stored on another component of network device **400**, including, but not limited to, non-transitory media inside processor-readable removable storage device **436**, processor-readable stationary storage device **434**, or any other computer-readable storage device within network device **400**, or even external to network device **400**. Data storage **410** may include, for example, file store **412**, and shadow store **416**.

Applications **420** may include computer executable instructions which, when executed by network device **400**, transmit, receive, and/or otherwise process messages (e.g., SMS, Multimedia Messaging Service (MMS), Instant Message (IM), email, and/or other messages), audio, video, and enable telecommunication with another user of another mobile device. Other examples of application programs include calendars, search programs, email client applications, IM applications, SMS applications, Voice Over Internet Protocol (VOIP) applications, contact managers, task managers, transcoders, database programs, word processing programs, security applications, spreadsheet programs, games, search programs, and so forth. Applications **420** may include, for example, file cloning application **422**, and file system application **424**.

Generalized File Cloning Operation

FIGS. **5**A-**5**D illustrate logical schematics showing portions of file cloning procedure **500** in accordance with at least one of the various embodiments.

In at least one of the various embodiments, a file system may include multiple files comprising inodes and data blocks. Each inodes may be associated with a file and may include meta-data such as, block count, last-access-time, file size, permissions, file name, pointers to the file data blocks, or the like.

In at least one of the various embodiments, inodes may reference thousands or millions of the data blocks. Data blocks may be associated with an inode using a variety of well-know data structures, including B-trees, linked lists, or the like.

In at least one of the various embodiments, in distributed file systems files and/or inodes may be distributed across one or more physical computing devices (nodes) arranged in the cluster. Also, nodes may include virtual machine nodes that may be running under the supervision of a hypervisor.

In at least one of the various embodiments, data blocks owned by an inode may be distributed among one or more nodes in the distributed file system. In at least one of the various embodiments, data blocks may be grouped in protection groups that include data blocks and error correction blocks. While not depicted in the figures, data blocks, reference blocks, inodes, shadow stores, shadow store blocks, or the like, may be distributed among nodes in a distributed file system.

FIG. **5**A represents the logical schematic of the first stage (s) for file cloning procedure **500**. In at least one of the various embodiments, inode **502** may include references to data blocks **504**-**508**. These blocks may represent the data comprising the file. In at least one of the various embodiments, the data included in the data blocks may be text and/or binary data, or a combination thereof. In at least one of the various embodiments, inode **502** and data blocks **504**-**508** may be stored on different/separate nodes in a distributed file system. In at least one of the various embodiments, the data structures comprising the inode and data blocks may be file based rather than device block based.

In at least one of the various embodiments, users/processes that access the data in a file corresponding to inode **502** may use file system calls that locate and/or retrieve inode **502**. Further, the data structures in the inode may enable the data blocks to be located. Also, inode **502** may enable additional blocks to be associated with the file as needed (e.g., for writes and/or create operations).

In at least one of the various embodiments, if a user or process initiates a file clone operation, another inode such as inode **510** may be generated. In at least one of the various embodiments, even though inode **510** represents a separate file some of the meta-data values of inode **510** may be the same as inode **502**, such as, file size, block count, access dates, permissions, or the like. In at least one of the various embodiments, the inode associated with a file clone may be generated with different permissions and access levels than the source inode.

Additionally, in at least one of the various embodiments, shadow store **512** also may be generated. In at least one of the various embodiments, shadow store **512** may be similar to an inode except that for most users and/or processes the shadow store inode is invisible and/or inaccessible. In at least one of the various embodiments, inode **502**, inode **510**, or shadow store **512** may be generated on separate file system nodes. If the target inode and the shadow store are initialized, the generation of the file clone of inode **502** may continue. Also, in at least one of the various embodiments, file cloning application may employ an existing shadow store as part of the file cloning procedure.

FIG. **5**B represents the logical schematic of a portion of the early stage(s) for file cloning procedure **500**. In at least one of the various embodiments, file cloning application **422** may continue generating a file clone of inode **502** by transferring data blocks owned by inode **502** to shadow store **512**.

In at least one of the various embodiments, file cloning application **422** may determine a data region owned by inode **502** to transfer to the shadow store. In at least one of the various embodiments, a data region may be one or more blocks and/or portions of blocks. For ease of description, the embodiment depicted in FIG. **5**B determines each data region to be a single block. One of ordinary skill in the art will appreciate that using a data region that includes a single data block is non-limiting. In at least one of the various embodiments, a data region may be determined to include multiple data blocks.

As shown in FIG. **5**B, in at least one of the various embodiments, the data included block **504** is selected for transfer to shadow store **512**. In at least one of the various embodiments, this may result in the generation of shadow store block **514**. Further, in at least one of the various embodiments, block **504** may be changed from a data block to a reference block that reference's shadow store block **514**. Pointer **516**, illustrates that block **504** references data stored in shadow store **512** at block **514**.

In at least one of the various embodiments, pointer **516** points into index **518**. In at least one of the various embodiments, index **518** may further indentify the specific shadow store block that includes the data that used to be in block **504**. Pointer **520** illustrates the indirection between the reference block **504** and shadow store block **514**.

In at least one of the various embodiments, index **518** abstracts the data structures and/or indexing employed in the shadow store. In at least one of the various embodiments, the file cloning application may employ index **518** and pointers **520** to enable a shadow store to arrange and/or layout its shadow store blocks independently from the order that block may have been arranged in the source the file. Thus, the layout/order of shadow store blocks may be arranged independently of their order in the inodes. The figures and description herein show the data blocks, reference blocks and shadow store blocks in the same corresponding order/position for brevity and convenience to aid in clarifying the description.

In at least one of the various embodiments, a shadow store may include shadow store blocks referenced by file unrelated to the current file cloning operation. Further, in at least one of the various embodiments, index **518** enables the file cloning application to arrange and/or optimize the shadow store blocks independent from the reference blocks that may be pointing to the shadow store. In at least one of the various embodiments, index **518** and pointers **520** may be implemented using well-know data structures such as, lookup tables, b-trees, hash tables, or the like.

In at least one of the various embodiments, if the first determined data region from inode **502** has been transferred to the shadow store, the file cloning application may generate reference block **522** and associate it with inode **510**. In at least one of the various embodiments, reference block **522** contains a reference to shadow store block **514**. Pointer **524** illustrates that reference block **522** points to index **518** in shadow store **512**. In at least one of the various embodiments, because inode **510** is a clone of inode **502**, it may reference the same shadow store block (e.g., block **514**) as reference block **504**.

In at least one of the various embodiments, shadow store **512** may track the number of references to a shadow store block using reference counter **526**. In this example, since reference block **504** and reference block **522** point to shadow store block **514**, the reference counter corresponding to shadow store block **514** has a value of two. In at least one of the various embodiments, reference counter **526** may increase as the number reference blocks pointing to shadow store block **514** increases. Likewise, in at least one of the various embodiments, the value of reference counter **526** may decrease as the number of reference blocks pointing to shadow store block **514** decrease.

FIG. **5**C represents the logical schematic of a portion of further stage(s) for file cloning procedure **500** in accordance with at least one of the embodiments. In at least one of the various embodiments, file cloning application **422** may continue generating a file clone for inode **502** by transferring data blocks owned by inode **502** to shadow store **512**.

The schematic in FIG. **5**C is similar to FIG. **5**B, except it depicts the next data region owned by inode **502** being transferred to shadow store **512**. As such, the data from block **506** may be transferred to shadow store block **530** in shadow store **512**. Pointer **528** may point from reference block **506** to index **518**. Further, in at least one of the various embodiments, pointers **520** may be updated to include pointing to reference block **530**.

Also, in at least one of the various embodiments, new reference block **532** may be generated and associated with inode **510**. Reference block **532** may point to shadow store block **530** through pointer **534** and pointers **520**.

Furthermore, reference counter **526** may be updated to store the reference count for shadow store block **530**. In at least one of the various embodiments, because two reference blocks (e.g., reference block **506** and reference block **532**) may be pointing to shadow store block **530**, the reference count for both shadow store blocks is two.

FIG. **5**D represents the logical schematic of a portion of the further stage(s) for file cloning procedure **500**. In FIG. **5**D, in at least one of the various embodiments, the cloning process has progressed following the same pattern as in FIGS. **5**B and **5**C. The data from block **508** may be transferred to shadow store block **538**. Likewise, for inode **510** reference block **540** may be generated. In at least one of the various embodiments, pointers **536** and **542** may reference index **518** of shadow store **512**.

Further, in at least one of the various embodiments, reference counter **526** may be updated to include the reference count for block **538**. In this example, because block **508** and block **540** indirectly reference block **538**, the corresponding reference count value for shadow store block **538** may be two.

In at least one of the various embodiments, reference counting may be implemented using well-known data structures, such as, arrays, linked lists, or the like. Further, in at least one of the various embodiments, reference counters may be included as part of the shadow store blocks such as block **514**.

In at least one of the various embodiments, reference counter **526** may be implemented in a data structure separate from the shadow store blocks. Separating the reference counter data structure from the shadow store block data-structures may enable the fields/data in the reference counter to be accessed separate from the data blocks.

In at least one of the various embodiments, improved performance may be obtained by disentangling the locking of the reference counters with the locking of data blocks. For example, as references to shadow store block are added and removed the corresponding reference counters may be updated without locking the shadow store data blocks.

Further, in at least one of the various embodiments, reference counters, such as, reference counter **525**, may be arranged to use delta data enabling delta write locks and delta read locks to be acquired on the reference counter data. (See, FIG. **11** and discussion about delta locks below.)

In at least one of the various embodiments, data blocks owned by inodes may be reference using an address scheme such as, "block 0: disk0, offset 1000; block 1: disk0, offset 2000; block 1: disk1, offset 3000." In at least one of the various embodiments, the data block addresses may be stored in well-known data structures such as, lookup tables, arrays, b-trees, or the like.

In at least one of the various embodiments, reference blocks may use a address scheme such as, "block 0: shadow store 0, offset 1000; block 1: shadow store 0, offset 2000, block 2: shadow store 0, offset 3000." In at least one of the various embodiments, the reference block addresses may resolve to an index data structure in the shadow store. The index in the shadow store may include information to maps the reference block address to the corresponding shadow store block.

In at least one of the various embodiments, at the completion of a file cloning operation users may consider the source file and target file as two separate files. In at least one of the various embodiments, the sharing of the shadow store blocks may be hidden from the view of users (and user-space processes).

Cloning Previously Cloned Files

In at least one of the various embodiments, file cloning application **422** may be employed to generate a file clone from a source file that is a product/participant of a file cloning operation. In this case, the source file inode may own/include one or more reference blocks that point to another shadow store. FIG. **6**A illustrates, for at least one of the various embodiments, a logical schematic of a source file that includes at least one block referencing another shadow store.

In at least one of the various embodiments, this initial state may be similar to the schematic illustrated in FIG. **5**A. Inode **602** may represent the file that may be cloned. Inode **602** includes three blocks, data block **604**, reference block **606**, and data block **608**. However, in this embodiment, inode **602** may have been cloned previously (e.g., generally following the procedure described in conjunction with FIGS. **5**A-**5**D). Thus, in at least one of the various embodiments, all or some of the blocks included/owned by inode **602** may be reference blocks that reference one or more blocks in a shadow store that may be correspond to a previous file cloning operation.

In the example depicted in FIG. **6**A, for at least one of the embodiments, block **606** is a reference block that points to shadow store **610**. Pointer **614** indicates that reference block **606** may be referencing index **616**. In at least one of the various embodiments, index **616** maintains the reference to shadow store block **612** shown by pointer **618**.

Further, in at least one of the various embodiments, similar to shadow store **512**, reference counter **620** tracks the number of reference blocks pointed to shadow store blocks in shadow store **610**. Here, in this example, reference count **620** may have a value of one corresponding to reference block **606**.

In at least one of the various embodiments, cloning the file represented by inode **602** generally includes executing steps similar to those described in conjunction with FIGS. **5**A-**5**D. However, as illustrated in FIG. **6**B there may be differences.

FIG. **6**B shows for, at least one of the various embodiments, logical schematic **600** at the completion of a file clone operation. In this example, in at least one of the various embodiments, inode **602** may have been cloned to generate inode **622**. And, shadow store **624** may have been generated in conjunction with the file cloning operation.

In at least one of the various embodiments, at the completion of cloning inode **622** from inode **602**, two shadow stores may remain (e.g., shadow store **602** and shadow store **622**).

In at least one of the various embodiments, the data from block **604** and block **608** may be transferred to blocks owned by shadow store **624** and the block converted to reference blocks that point to shadow store **624**. However, in this example, reference block **606** points to shadow store **610**. In at least one of the various embodiments, file cloning application **422** may be arranged to leave reference block **606** pointing to shadow store **616** rather than generate a reference block that points to shadow shore **624**, or reference from shadow store block **612** to shadow store **624**. This at least avoids the operational expense of transferring data from shadow store block **612** to shadow store **624**. As well as, at least the expense and complexity of implementing a double indirection reference between shadow store block **612** and shadow store **624**.

In at least one of the various embodiments, in this example, reference block **628** of the target inode **622** corresponds to reference block **606** in source inode **602** thus rather than generating a reference to pointer to shadow store **624**, pointer **630** may be point to shadow store **610**. In at least one of the various embodiments, reference counter **620** for shadow store block **612** is incremented. (e.g., resulting in a value of two) because in FIG. **6**B two reference blocks (e.g., reference block **606** and reference block **628**) are shown as referencing shadow store block **612**.

In at least one of the various embodiments, in this example, two blocks (e.g., formerly data blocks now reference block **604** and reference block **608**) may be transferred to shadow store **624**. In at least one of the various embodiments, reference counter **626** may be generated to track the number of references to the shadow store blocks owned by shadow store **624**. Based on this example, in at least one of the various embodiments, the two shadow store blocks owned by shadow store **624** are each referenced by reference blocks owned by inode **602** and inode **622** thus reference counter **626** includes two fields/cells both set to value of two.

FIGS. **7**A-**7**B illustrate for at least one of the various embodiments logical schematic **700** that shows portions of a file cloning procedure of a source file having a snapshot.

In at least one of the various embodiments, to guarantee that a source file and a target file are identical a file cloning application may acquire file system locks on the source file and target file to prevent users/process from accessing the files while the file cloning operation in process.

However, in at least one of the various embodiments, in high performance file systems, including distributed file system it may be impractical to acquire file locks on the files participating in a file cloning operation. In cases with a many users trying to access files such broad locking policies would impact too many users to be practicable. Also, in cases with very large files the file cloning process may to take a relatively long time causing significant performance impacts on users of the files.

In at least one of the various embodiments, to at least avoid some of the issues caused by extended locking of the source file, file cloning application **422** may employ "snapshots" that preserve the state of a file at a particular point of time.

In at least one of the various embodiments, snapshots may be employed to establish point-in-time consistency and guarantee access to the state/contents of a file as the file it existed at the time the snapshot was generated. Thus, in at least one of the various embodiments, if a file clone is generated from a snapshot, the target file (e.g., the clone) may be at least guaranteed to contain the same contents as the source file contained when the snapshot was generated.

In at least one of the various embodiments, file system application **424** may be configured to automatically generate snapshots for files based on rules based policies that may define how often snapshots may be generated and/or which files may be included in the snapshots.

In at least one of the various embodiments, file cloning application **422** may receive requests to generate clones based on previous/older snapshot versions. Or, in at least one of the various embodiments, a snapshot of the source file may be generated immediately before the file cloning operation. In some cases, immediate snapshots made for the purpose of supporting a file cloning operation may be discarded at the completion of the file cloning operation. Otherwise, the snapshot may remain in place subsequent to the file cloning operation.

In at least one of the various embodiments, cloning a file based on a snapshot of the source file may enable other process and users to access the head version of source file (the "live" version). In at least one of the various embodiments, file system application **422** may employ various well-known data structures to implement a snapshot, such as b-trees, or the like.

In at least one of the various embodiments, rather than maintain a copy of each data block owned by an inode, snapshots may be configured to copy data blocks from a source file if the source file data block is modified (e.g., updated or deleted). In at least one of the various embodiments, this may reduce the time to generate a snapshot and the amount of storage space required. For example, snapshots made of large static files may be generated quickly by establishing a snapshot timestamp without copying a significant amount of data.

In at least one of the various embodiments, data blocks may be copied to the snapshot as data blocks in the snapshot source file are modified. For short lived snapshots, in at least one of the various embodiments, snapshots may be generated and discarded before many data blocks are copied. Alternatively, in at least one of the various embodiments, depending on the popularity of the source file, the longer time a snapshot is active/available, the increased likelihood of data blocks being transferred to it.

In at least one of the various embodiments, the example embodiment depicted in FIG. **7**A illustrates an inode (e.g., inode **702**) having three data blocks (e.g., data block **704**, data block **706**, and data block **708**). In at least one of the various embodiments, snapshot **710** may be a snapshot of the file represented by inode **702**. In at least one of the various embodiments, snapshot **710** may include ditto block **712**, data block **714**, and ditto block **716**.

In the example depicted by FIG. **7**A, in at least one of the various embodiments, data block **714** has been transferred to snapshot **710** because data block **706** was modified subsequent to the generation of snapshot **710**. In this example, data block **704** and data block **706** remain unchanged from the time snapshot **710** was generated thus they have not been copied to snapshot **710**. In at least one of the various embodiments, ditto blocks and/or ditto regions may be used to indicate that a portion of the corresponding file remains unchanged. Likewise, data blocks, such as data block **714**, that are in the snapshot may be copies of the data block as it was at the time the snapshot was generated. For example, in at least one of the various embodiments, data block **714** contains data that is a older/prior version than the data block **706**.

FIG. **7**B shows logical schematic **700**, for at least one of the various embodiments, of completed a file cloning operation where a snapshot is employed to preserve a point-in-time state of the source file.

In at least one of the various embodiments, inode **718** may be clone of inode **702** based on snapshot **710** of inode **702**. In at least one of the various embodiments, the generalized file cloning procedure described in conjunction with FIGS. **5**A-**5**D may be employed. However, in at least one of the various embodiments, if snapshot **710** contains data blocks, those data blocks may the ones transferred into the shadow store.

In FIG. **7**B, data block **714** maybe transferred to shadow store **720**. Further, because block **728** in inode **718** corresponds to block **714**, rather than data block **706**, it may be arranged to reference shadow store **720**. Note that in the example depicted in FIG. **7**B, block **706** remains a data block rather than being converted to a reference block because the clone, inode **718** in the example, is based on the file version held in snapshot **710** rather than the head version of inode **702**. Arrow **722** illustrates how block **714** may be transferred to block **726** in shadow store **720**. Further, data block **714** may be replaced by a reference block pointing to shadow store block **726**.

In at least one of the various embodiments, generating file clones based on snapshots may be reflected in the shadow store reference count. In this example, reference counter **724** tracks that shadow store block **726** (corresponding to the second cell in reference counter **724**) has a two references pointing to it. In this example, the reference counter value of two indicates that reference block **728** is pointing to block **726** and reference block **714** is pointing to block **726**. The other two cells in reference counter **724** also have a value of two corresponding to the reference blocks from inode **702** and inode **718** that reference shadow store blocks in shadow store **720**.

Writing into File Clones

FIG. **8** depicts, for at least one of the various embodiments, logical schematic **800** showing result of a write operation. In particular, the example illustrates, for at least one of the various embodiments, how relevant data objects may be arranged subsequent a write into a file clone.

In this example, in at least one of the various embodiments, inode **802** and inode **804** may be file clones. As file clones they may include reference blocks to point to shadow store block in shadow store **806**. In at least one of the various embodiments, if a user process tries to write to a portion of inode **804** that corresponds to reference block **808** (e.g., the block in the second position of inode **804**), file system application **424** may copy data from shadow store block **812** into converting reference block **808** into a data block before (or as part of) the write operation. Because reference block **810** remains unchanged from the time the file clone was generated it continues to point to reference block **812** in shadow store **806**.

In at least one of the various embodiments, as writes or modifications are made to the file clones, reference blocks that point to shadow store blocks may be converted to data block by copying the data in the corresponding shadow store blocks to the inodes.

Accordingly, in at least one of the various embodiments, shadow store reference counters such as reference counter **814** may track if shadow store blocks are have dependent reference blocks by at least decrementing the reference counts corresponding to each copied block.

FIG. **9** illustrates for at least one of the various embodiments how the file system application may process read operations operation targeted at file clones. In at least one of the various embodiments, logical schematic **900** models a portion of a file system that includes two cloned inodes, inode **902** and inode **904**, and the corresponding shadow store **906**. As indicated in FIG. **9**, for at least this example, each reference block in the cloned inodes point to shadow store blocks in shadow store **906**.

In at least one of the various embodiments, for example, if file system application **424** receives a read request to read data that corresponds to reference block **908**, the file system use the meta-data included in inode **902** to identify the reference block **908** targeted by the read request. Next, because reference block **908** points to a shadow store block owned by shadow store **906**, the file system may follow the pointers and/or indirect references associated with reference block **908** to retrieve the data from the appropriate shadow store block for the read request.

During a read operation, in at least one of the various embodiments, the reference blocks in the inode may remain pointing to shadow store blocks in shadow store **906** because the data in the blocks remains unmodified after a read operation. Thus, in at least one of the various embodiments, the copy operations associated with a write are unnecessary.

In at least one of the various embodiments, caching may be employed by file system application to improve at least read performance. In at least one of the various embodiments, the inode being targeted by a read request may cache the read data locally in an in-memory cache.

In at least one of the various embodiments, inodes may be part of a multi-node/multi-server distributed file system. Accordingly, the shadow store may be on a different server and/or a different physical network device than the inodes. Thus, in at least one of the various embodiments, a local in-memory cache of read blocks and/or portions of read block may be employed to reduce the response time for subsequent reads of the same data. Each inode may generate it own in-memory cache which may lead to redundant data copies in the local caches. The redundant data may increase memory requirements for the file system.

Alternatively, in at least one of the various embodiments, the shadow store may generate an in-memory cache for each read request. In at least one of the various embodiments, this may eliminate storage redundancies that may arise if local inode caches are employed. In at least one of the various embodiments, the reduced redundancy may reduce the amount of memory consumed by the file system application.

Protection Groups/Forward Error Correction

In at least one of the various embodiments, data blocks may be grouped into file-based protection groups that may be arranged to support error correction and/or data validation.

In at least one of the various embodiments, file system application **424** may employ various forward error correction (FEC) techniques to protect against data loss that may be caused by device and/or system failure. In at least one of the various embodiments, various well-known techniques may be applied that offer different levels of protection. In at least one of the various embodiments, the particular FEC technique and arrangement of the protection groups may vary depending on operator/user preferences and according to the level protection desired.

FIG. **10** illustrates data structures for at least one of the various embodiments that may be employed by file system application **424** for FEC. A data structure such as FEC table **1002** may be employed to provide FEC for data blocks owned by an inode. Likewise, FEC table **1004** may be employed to provide FEC for shadow store blocks owned by a shadow store.

In at least one of the various embodiments, the FEC table in FIG. **10** may be arranged into two columns of data blocks and one column for protection data. This may provide single protection FEC. In at least one of the various embodiments, additional protection columns may be used to provide improved protection of the data in exchange for increased storage requirements.

In at least one of the various embodiments, sixteen data blocks and eight FEC blocks may be arranged in each table. The data blocks in tables **1002** and **1004** include labels B0, B1 . . . B15 used to indicate the position of the blocks within the tables. Also, the FEC blocks are labeled F0, F1, . . . , F7. The labels do not represent the data in the block, thus block B0 in table **1002** is unlikely to have the same data/contents as block B0 in table **1004**. (Each table has a B0 block and they usually include different data.) In at least one of the various embodiments, each row in the tables may comprise a protection group.

In at least one of the various embodiments, one type of FEC may comprise Exclusive-Or'ing (XOR) each data block in a protection group with each to producing the contents of a FEC block. Thus, in at least one of the various embodiments, if one data block in the protection group is lost or corrupted, the well-known Boolean logic properties of the XOR operation enable the remaining data block and the FEC block in the protection group to be used to reproduce the contents of one lost or corrupt block.

For example, in at least one of the various embodiments, block **1006** XOR'd with the block **1008** generates FEC block **1010** (e.g., B0⊗B8=F0). If the data in block B0 **1006** is lost or corrupted XOR'ing the surviving block, B8 **1008** with the FEC block **1010** (F0) regenerates the data for block B0 **1006** (e.g., F0⊗B8=B0). Likewise, if the data in block **1008** (B8) is lost or corrupted the data in block **1006** (B0) may be XOR'd with FEC block **1010** (F0) to reproduce the data for block **1008** (B8) (e.g., F0⊗B0=B8).

In at least one of the various embodiments, if a data block in a protection group is a reference block pointing to a shadow store block, the reference block may not be used to the generate the FEC block for the protection group. In at least one of the various embodiments, reference blocks in protection groups may be treated as zero valued blocks.

For example, in at least one of the various embodiments, in FEC table **1002**, block **1012** (B5) may be a data block and block **1014** may be a reference block (indicated in the figure by the empty table cell with a "slash" through it). In this case, in at least one of the various embodiments, the FEC block that corresponds to block **1012** may be generated by XOR'ing block **1012** with a zero block (e.g., B2⊗0=F0) resulting a FEC block (F2) that has the same value as the data block based on the properties of XOR (e.g., B2⊗0=B2).

In at least one of the various embodiments, blocks in a protection group that reference a shadow store block, point a shadow store block (data block) in the shadow store protection group. In at least one of the various embodiments, the shadow store protection group may be used to provide protection to the shadow store blocks rather than the protection groups associated with other inodes.

For example, in at least one of the various embodiments, since block **1014** is a reference block, pointer **1020** may reference a particular shadow store block in the shadow store protection group. In this example, in at least one of the various embodiments, pointer **1020** points to shadow store block **1018** in the shadow store protection group. Thus, data protection for the data pointed to reference block **1014** may be provided by XOR'ing block **1016** with block **1018** to produce FEC block **1022** that may be stored in a shadow store protection group.

In at least one of the various embodiments, in a distributed file system each element (e.g., data blocks and FEC blocks) comprising a protection group may be stored on a separate node (network device or blade). Further, in at least one of the various embodiments, protection group elements may be stored on separate disk drives on the same node.

Delta Locks

FIG. **11** illustrates, for at least one of the various embodiments, relationships between file/memory lock types (e.g., delta read locks, delta write locks, shared locks, and exclusive locks). Table **1100** shows how lock types may be compatible with other lock types. In at least one of the various embodiments, a delta read lock may require that the non-delta data of the locked resource remains undisturbed (e.g., read-only). Accordingly, delta read locks may be compatible with other delta read locks, delta write locks, and shared locks because these locks may ensure that the non-delta data of a locked resource remains unchanged.

As shown in table **1100**, delta write locks may be compatible with other delta write locks and delta read locks. Writers holding delta write locks may modify delta data and may not modify non-delta data. This behavior may be incompatible shared locks because shared locks may not recognize a distinction between delta and non-delta data. Rather, shared locks may require that the entire resource remain undisturbed. Further, as expected, exclusive locks may be incompatible with all other locks because an exclusive lock may signal that the lock holder can write or read the entire resource and that the resource may not be altered by other writers or readers. Note, that in at least one of the various embodiments, an exclusive lock may lock all the resource data without considering whether the resource may have been partitioned into delta data or non-delta data.

Accordingly, in at least one of the various embodiments, a writer may immediately obtain a delta write lock on an inode if all other locks on the inode may be delta write locks and/or delta read locks. If a writer tries to obtain a delta write lock on an inode where a reader has already obtained a shared lock the writer may have to wait until the shared lock is released before obtaining the delta write lock. However, in at least one of the various embodiments, as depicted in table **1100**, a reader trying to obtain a delta read lock may proceed without delay as long as there is not an exclusive lock on the targeted inode.

In at least one of the various embodiments, enabling multiple writers to concurrently obtain delta write locks on the same inode may enable multiple writers to concurrently write to the same file. In at least one of the various embodiments, writers may obtain concurrent delta write locks on an inode to execute concurrent writes to the file if the writers intend to modify separate portions of the file. If the file and/or inode, is under a lock type incompatible with delta writes (e.g., shared locks, exclusive locks) and/or if another writer with a lock may be writing to the same part of the file (the same data blocks), the writer may be unable to obtain a delta write lock for writing. Accordingly, if a delta write lock may not be obtained, a writer may have to wait until the incompatible lock(s) on the file are released by their respective lock holders.

In at least one of the various embodiments, at least the reference counters used to track number of reference blocks that may be pointing to shadow store blocks may be implemented using delta data. Thus, in at least one of the various embodiments, processes may take delta write locks on the reference counter data structure when incrementing or decrementing the counts. This, at least enables one or more processes or threads to concurrently decrement and/or incremented the reference counts using journals delta.

In at least one of the various embodiments, each process decrementing a reference count may record a "−1" in the delta journal. Likewise, in at least one of the various embodiments, each process incrementing a reference counter may record a "+1" in the delta journal. Later, in at least one of the embodiments, a house keeping process may sum the journal delta to determine the current value of the reference counter.

Generalized Operations

FIG. **12** shows a flowchart for process **1200** for generating a file clone in accordance with at least one of the various embodiments. After a start block, in at least one of the various embodiments, at block **1202**, a file cloning application may receive a request to generate a file clone.

At decision block **1204**, in at least one of the various embodiments, if the request to generate a file clone includes a snapshot, control may move to block **1208**. Otherwise, in at least one of the various embodiments, control may move block **1206**.

In at least one of the various embodiments, if a request identifies a snapshot that includes the source file to use as a basis for generating in the file clone that file clone may be based off of the identified snapshot. In at least one of the various embodiments, the relevant snapshot may be determined by an identifier included with the file cloning request. Or, in at least one of the various embodiments, the relevant snapshot may be determined by applying rule based policies and/or configuration settings.

At block **1206**, in at least one of the various embodiments, generate a snapshot that includes the source file or acquire a lock on the source file. In at least one of the various embodiments, file system application **424** may be configured to automatically generate a snapshot that includes the source file if the initial file cloning request does not identify a snapshot. In these cases, in at least one of the various embodiments, the file system application **425** may generate a snapshot that preserves the state of the source file.

Alternatively, in at least one of the various embodiments, the file cloning application may acquire a lock on the source file that the contents of the file from changing during the file cloning process.

At block **1208**, in at least one of the various embodiments, the file cloning application may generate a target inode and a shadow store. In at least one of the various embodiments, the target inode may be the result of the file cloning operation. In at least one of the various embodiments, one or more target inodes may be generated based on parameters in the received request. For example, a user may request to create multiple clones of the same source file.

In at least one of the various embodiments, the target inode (s) and the shadow store may be generated absent reference blocks and/or data blocks.

At block **1210**, in at least one of the various embodiments, the file cloning application may determine the region of the source file to transfer to the shadow store. In at least one of the various embodiments, the file cloning application may advance through the data blocks owned by the source file to determine the source file regions. In at least one of the various embodiments, source file data regions may include one or more blocks. Also, in at least one of the various embodiments, source data regions may include partial data blocks.

In at least one of the various embodiments, if a snapshot is being used, the file cloning application may check the relevant snapshot for source file data blocks to transfer to the shadow store. In at least one of the various embodiments, if relevant data blocks may be found in relevant snapshots, those data blocks may be transferred to the shadow store. Alternatively, if data blocks may be absent from the snapshot the file cloning application may transfer the data block directly from the source file.

At decision block **1212**, in at least one of the various embodiments, if the source file data region being transferred includes reference blocks pointing to another shadow store, control may move to block **1214**. Otherwise, in at least one of the various embodiments, control may move to block **1216**.

At block **1214**, in at least one of the various embodiments, the file cloning application may generate reference blocks corresponding to the reference blocks found in source file data region. In at least one of the various embodiments, the generated reference blocks may include pointers to shadow store blocks in the other shadow store. Further, in at least one of the various embodiments, the generated reference blocks may be attached and/or associated with the target inode(s) using well-known data structures.

At block **1216**, in at least one of the various embodiments, the file cloning application may transfer the determined source file data regions to the shadow store and generate corresponding reference blocks in the source file and target file(s). In at least one of the various embodiments, the data blocks in the source file may be replaced by reference blocks that may point to corresponding shadow store blocks in the shadow store. Similarly, other reference blocks that point to the corresponding shadow store blocks in the shadow store may be generated for each target file.

At decision block **1218**, in at least one of the various embodiments, if source file data regions remain to be cloned, control may loop back to block **1210**. Otherwise, in at least one of the various embodiments, control may be returned to a calling process.

FIG. **13** shows a flowchart for process **1300** for determining the source file data regions for transferring to a shadow store in accordance with at least one of the various embodiments. After a start block at block **1302**, in at least one of the various embodiments, determine the data region of the source file to transfer to the shadow store for a file cloning request that designates a snapshot.

At block **1304**, in at least one of the various embodiments, the file cloning application may examine the snapshot to identify snapshot regions that may be included in the source file data region. For example, if the source file data region includes a range of data blocks, such as block 0 through block 3, the snapshot may be examined to determine if it includes data blocks corresponding to the source file block 0-3.

In at least one of the various embodiments, if the subsequent to the creation of the snapshot, data blocks in the source file were modified, versions of the data blocks that correspond to the point-in-time the snapshot was generated may be preserved in the snapshot. In at least one of the various embodiments, the file cloning application may examine the snapshot regions that correspond to the source file data region. In at least one of the various embodiments, if corresponding data in the snapshot regions is discovered, the file cloning application may be determined that the data blocks in the snapshot may relevant to the cloning operation. The newer data blocks that may have been modified subsequent to the point-in-time the snapshot was generated may be excluded from the file clones.

At block **1306**, in at least one of the various embodiments, determine if partial regions may be transferred to the shadow store. In at least one of the various embodiments, a snapshot may include partial regions corresponding to partial regions in the source file. In at least one of the various embodiments, partial regions may include partial data blocks.

In at least one of the various embodiments, because the data region may be small the file cloning application may analyze the partial regions to determine if the partial region should be transferred to the shadow store.

At block **1308**, in at least one of the various embodiments, the file cloning application may transfer the data regions and/or partial regions to the shadow store. In at least one of the various embodiments, if the determined data regions have corresponding data in the snapshot, data from the snapshot may be transferred to the shadow store. Otherwise, in at least one of the various embodiments, the source file data regions may be transferred to the shadow store from the source file rather than the snapshot. Next, control may be returned to a calling process.

FIG. **14** shows a flowchart for process **1400** for transferring partial regions of a file to a shadow store in accordance with at least one of the various embodiments. After a start block, at block **1402**, in at least one of the various embodiments, the file cloning application may characterize a partial region before determining if it may be transferred to a shadow store.

At block **1404**, in at least one of the various embodiments, apply the partial region transfer policy based on the characterization of the partial region. In at least one of the various embodiments, the file cloning application may identify partial regions that may be cloned.

In at least one of the various embodiments, the size of a partial region may indicate that it may be more efficient to copy the data in the partial region directly to the target files rather to a shadow store. For small regions this may be more efficient than transferring the data to a shadow store by avoiding the overhead of generating the corresponding reference blocks in the source file and the target file, reference counters, or the like.

In at least one of the various embodiments, a variety of factors, including configuration properties, system properties, application properties, or the like, may be considered if determining if partial regions should be transferred to a shadow store. In at least one of the various embodiments, properties considered may include, region size thresholds, number of nodes, average file size, source file size, average number connections/users, popularity of source file, popularity of the partial region, or the like.

In at least one of the various embodiments, the particular properties, rules, threshold values, or the like, may be stored in configuration files/databases, received from user-interfaces, determined based on policy rules/formals, or the like.

At decision block **1406**, in at least one of the various embodiments, if transferring the partial region to the shadow store is determined to be suboptimal control may move to block **1408**. Otherwise, in at least one of the various embodiments, control may move to block **1410**.

At block **1408**, in at least one of the various embodiments, the file cloning application may copy a duplicate of the partial region to the target files. In at least one of the various embodiments, if the partial region may be copied to the target files the file cloning application may not generate reference blocks for the source file inode and for the target file inode. If the data in the partial regions is duplicated, generating corresponding reference blocks may be unnecessary. Also, in at least one of the various embodiments, if the partial region is not transferred to the shadow store, the reference counters in the shadow may remain unchanged.

At block **1410**, in at least one of the various embodiments, the file cloning application may transfer the partial region to the shadow store and generate corresponding reference blocks in the source file and the target files. Further, in at least one of the various embodiments, if the partial region may be transferred to the shadow pointer the corresponding reference counters may be generated to track the number of references made to the partial regions.

FIG. **15** shows a flowchart for process **1500** for writing to a file clone in accordance with at least one of the various embodiments. After a start block, at block **1502**, in at least one of the various embodiments, a request to write to a target file may be received. In at least one of the various embodiments, a write request may include sufficient information to identify the portion of the target file that may be affected by the write operation. For example, in at least one of the various embodiments, the write request may include an inode ID, a buffer of data, an offset into the file, or the like. Or, in at least one of the various embodiments, the write request may include a buffer of data an indicator that the data should be appended to the file at the end.

At decision block **1504**, in at least one of the various embodiments, if the block that is the target of write may be a reference block pointing to a shadow store, control may move to block **1506**. Otherwise, in at least one of the various embodiments, control may move to block **1510**.

In at least one of the various embodiments, if the write request may resolve to an append operation, the shadow store may not be involved. This may be because the write may generate a new data block that may be appended to the existing blocks owned by the target file that does not affect reference blocks that may point to a shadow store.

In at least one of the various embodiments, if the write request resolves to a reference block in the target file, the write request may be targeted to modify a region of the target file that is currently stored in the shadow store.

At block **1506**, in at least one of the various embodiments, the file cloning application may copy the contents/data from the shadow store block that corresponds to the target block into a data block in the target file (replacing the reference block with the data block).

At block **1508**, in at least one of the various embodiments, the file cloning application may update the reference counters in the shadow store corresponding to the target block.

In at least one of the various embodiments, reference blocks in the target file may be replaced by data blocks that include data copied from the shadow store. Thus, in at least one of the various embodiments, reference counters in the shadow stores may be decremented to reflect that the targeted file may no longer be referencing the shadow store blocks that were copied.

In at least one of the various embodiments, if a shadow store reference count for a shadow store block reaches zero, the data block may be released by the shadow store because no remaining file clone reference block point the shadow store block.

In at least one of the various embodiments, shadow store blocks determined to have reference counts of zero may be queued for garbage collection/clean-up by a house keeping process rather than being cleaned up immediately after the reference counts reach zero.

At block **1510**, in at least one of the various embodiments, the write may be executed by storing the write data into the appropriate data block in the target file. In at least one of the various embodiments, at this point the shadow store block and the target file block have different content values and have different state.

At decision block **1512**, in at least one of the various embodiments, if there may be additional write requests, control may loop back to block **1502**. Otherwise, in at least one of the various embodiments, control may be returned to a calling process.

FIG. **16** shows a flowchart for process **1600** for reading data from a file clone in accordance with at least one of the various embodiments. After a start block, at block **1602**, in at least one of the various embodiments, a request to read data from a source file may be received.

At decision block **1604**, in at least one of the various embodiments, if the data for the read request is in the local cache control may move to block **1606**. Otherwise, in at least one of the various embodiments, control may move to decision block **1608**.

At decision block **1606**, in at least one of the various embodiments, the file system application may retrieve the data for the read request from the local cache.

In at least one of the various embodiments, if the data for the read request is found in the local cache, it may be used directly avoiding the overhead of retrieving the data from a shadow store.

At decision block **1608**, in at least one of the various embodiments, if the source block is a reference block pointing to a shadow store block, control may move to block **1612**. Otherwise, in at least one of the various embodiments, control may move to block **1610**.

At block **1610**, in at least one of the various embodiments, retrieve the data corresponding to the read request the source file. In at least one of the various embodiments, if the read resolves to data block that is not referencing a shadow store that data may retrieved from the source file data blocks.

At block **1612**, in at least one of the various embodiments, retrieve the data corresponding to the read request from the shadow store. In at least one of the various embodiments, because the read request resolves to a reference block the data for the read may be located in a shadow store. Thus, in at least one of the various embodiments, the reference block pointers may be followed to determine the shadow store that may have the requested data held in a shadow store block. Further, in at least one of the various embodiment, because this is a read request, the content of the shadow store block may remain unchanged. Accordingly, in at least one of the various embodiments, the reference blocks in the source file that correspond to the read request may remain in place.

At block **1614**, in at least one of the various embodiments, the retrieved data may be stored in the appropriate cache. In at least one of the various embodiments, data retrieved from the shadow store and/or the source file in response to the read request may be stored in a in-memory cache that may be local to the source file inode.

Also, in at least one of the various embodiments, an in-memory cache may be generated local to the shadow store.

At block **1616**, in at least one of the various embodiments, the retrieved data may be provided to the user or process that initiated the read request.

At decision block **1618**, in at least one of the various embodiments, if more read requests may remain to be processed, control may loop back to block **1602**.

It will be understood that figures, and combinations of actions in the flowchart-like illustrations, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions executing on the processor create a means for implementing the actions specified in the flowchart blocks. The computer program instructions may be executed by a processor to cause a series of operational actions to be performed by the processor to produce a computer implemented process for implementing the actions specified in the flowchart block or blocks. These program instructions may be stored on some type of machine readable storage media, such as processor readable non-transitive storage media, or the like.

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A method for cloning files in a file system for a plurality of network devices, wherein at least one network device is operative to perform actions, comprising:

in response to a request to clone a source file, generating at least one target file and generating at least one shadow store unless at least one existing shadow store is determined to be available;

determining each data region in a set of data regions that comprise the source file wherein a data region in the set of data regions is a set of block address ranges;

determining whether each data region in the source file is a source file data region or a shadow store data region;

transferring each source file data block in each determined source file data region in the source file to the at least one shadow store without transferring preexisting reference blocks in the shadow store data regions to the at least one shadow store;

generating a shadow store block in the at least one shadow store corresponding to each transferred source file data block;

generating at least one reference block in a new shadow store data region for the source file that corresponds to each shadow store block, wherein each reference block replaces each corresponding source file data block in the source file;

generating at least one other reference block in the new shadow store data region corresponding to each shadow store block that is included in each target file; and

incrementing at least one reference count in the shadow store that corresponds to each generated reference block and each shadow store data region, wherein each target file is a clone of the source file that includes at least one reference block that references the shadow store.

2. The method of claim **1**, further comprising, if a snapshot identifier is absent from the request to clone the source file, generating a snapshot of the source file that is based on at least a state of the source file at a time of the request.

3. The method of claim **1**, further comprising if the request to clone the source file is associated with a snapshot that includes at least one data block older than a corresponding data block in at least one determined data region of the source file, transferring the at least one older data block from the snapshot to the at least one shadow store.

4. The method of claim **1**, further comprising:

receiving a request to write data to a file in the file system; and

if the received request to write data to the file resolves to a reference block instead of a data block in the file, performing further actions, including:

copying the shadow store block pointed to by the reference block in the file and converting it into a new data block in the file;

decrementing the reference counter in the shadow store that corresponds to the copied shadow store block; and

storing the write data into the new data block in the file.

5. The method of claim **1**, further comprising:

receiving a request to read data from a file in the file system; and

if the request to read data from the file resolves to at least one reference block in the file instead of a data block in the file, performing further actions, retrieving the requested read data from the at least one shadow store block corresponding to the at least one reference block.

6. The method of claim **1**, further comprising if a partial data block is both included in the determined data region of the source file and a size of the partial data block is less than a defined threshold, copying the partial data block to each target file.

7. The method of claim **1**, further comprising if a snapshot identifier is absent from the request to clone the source file, using a current version of the source file to generate the target file.

8. The method of claim **1**, further comprising, if the source file's determined data region of metadata consists entirely of reference blocks, generating a corresponding reference block in each target file without generating any new shadow store or shadow store block.

9. A network device for cloning files in a file system for a plurality of network devices over a network, comprising:

a memory for storing data and instructions;

a processor, wherein the processor is arranged to execute instructions that enable actions, including:

in response to a request to clone a source file, generating at least one target file and generating at least one shadow store unless at least one existing shadow store is determined to be available;

determining each data region in a set of data regions that comprise the source file wherein a data region in the set of data regions is a set of block address ranges;

determining whether each data region in the source file is a source file data region or a shadow store data region;

transferring each source file data block in each determined source file data region in the source file to the at least one shadow store without transferring preexisting reference blocks in the shadow store data regions to the at least one shadow store;

generating a shadow store block in the at least one shadow store corresponding to each transferred source file data block;

generating at least one reference block in a new shadow store data region for the source file that corresponds to each shadow store block, wherein each reference block replaces each corresponding source file data block in the source file;

generating at least one other reference block in the new shadow store data region corresponding to each shadow store block that is included in each target file; and

incrementing at least one reference count in the shadow store that corresponds to each generated reference block and each shadow store data region, wherein each target file is a clone of the source file that includes at least one reference block that references the shadow store.

10. The network device of claim **9**, further comprising, if a snapshot identifier is absent from the request to clone the source file, generating a snapshot of the source file that is based on at least a state of the source file at a time of the request.

11. The network device of claim 9, further comprising if the request to clone the source file is associated with a snapshot that includes at least one data block older than a corresponding data block in at least one determined data region of the source file, transferring the at least one older data block from the snapshot to the at least one shadow store.

12. The network device of claim 9, further comprising:

receiving a request to write data to a file in the file system; and

if the received request to write data to the file resolves to a reference block instead of a data block in the file, performing further actions, including:

copying the shadow store block pointed to by the reference block in the file and converting it into a new data block in the file;

decrementing the reference counter in the shadow store that corresponds to the copied shadow store block; and

storing the write data into the new data block in the file.

13. The network device of claim 9, further comprising:

receiving a request to read data from a file in the file system; and

if the request to read data from the file resolves to at least one reference block in the file instead of a data block in the file, performing further actions, retrieving the requested read data from the at least one shadow store block corresponding to the at least one reference block.

14. The network device of claim 9, further comprising if a partial data block is both included in the determined data region of the source file and a size of the partial data block is less than a defined threshold, copying the partial data block to each target file.

15. The network device of claim 9, further comprising if a snapshot identifier is absent from the request to clone the source file, using a current version of the source file to generate the target file.

16. The network device of claim 9, further comprising, if the source file's determined data region of metadata consists entirely of reference blocks, generating a corresponding reference block in each target file without generating any new shadow store or shadow store block.

17. A processor readable non-transitory storage media with instructions for cloning files in a file system for a plurality of network devices over a network, wherein execution of the instructions by a processor enables actions, comprising:

in response to a request to clone a source file, generating at least one target file and generating at least one shadow store unless at least one existing shadow store is determined to be available;

determining each data region in a set of data regions that comprise the source file wherein a data region in the set of data regions is a set of block address ranges;

determining whether each data region in the source file is a source file data region or a shadow store data region;

transferring each source file data block in each determined source file data region in the source file to the at least one shadow store without transferring preexisting reference blocks in the shadow store data regions to the at least one shadow store;

generating a shadow store block in the at least one shadow store corresponding to each transferred source file data block;

generating at least one reference block in a new shadow store data region for the source file that corresponds to each shadow store block, wherein each reference block replaces each corresponding source file data block in the source file;

generating at least one other reference block in the new shadow store data region corresponding to each shadow store block that is included in each target file; and

incrementing at least one reference count in the shadow store that corresponds to each generated reference block and each shadow store data region, wherein each target file is a clone of the source file that includes at least one reference block that references the shadow store.

18. The media of claim 17, further comprising, if a snapshot identifier is absent from the request to clone the source file, generating a snapshot of the source file that is based on at least a state of the source file at a time of the request.

19. The media of claim 17, further comprising if the request to clone the source file is associated with a snapshot that includes at least one data block older than a corresponding data block in at least one determined data region of the source file, transferring the at least one older data block from the snapshot to the at least one shadow store.

20. The media of claim 17, further comprising:

receiving a request to write data to a file in the file system; and

if the received request to write data to the file resolves to a reference block instead of a data block in the file, performing further actions, including:

copying the shadow store block pointed to by the reference block in the file and converting it into a new data block in the file;

decrementing the reference counter in the shadow store that corresponds to the copied shadow store block; and

storing the write data into the new data block in the file.

21. The media of claim 17, further comprising:

receiving a request to read data from a file in the file system; and

if the request to read data from the file resolves to at least one reference block in the file instead of a data block in the file, performing further actions, retrieving the requested read data from the at least one shadow store block corresponding to the at least one reference block.

22. The media of claim 17, further comprising if a partial data block is both included in the determined data region of the source file and a size of the partial data block is less than a defined threshold, copying the partial data block to each target file.

23. The media of claim 17, further comprising if a snapshot identifier is absent from the request to clone the source file, using a current version of the source file to generate the target file.

24. The media of claim 17, further comprising, if the source file's determined data region of metadata consists entirely of reference blocks, generating a corresponding reference block in each target file without generating any new shadow store or shadow store block.

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